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1991

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1991

ASSOCIATION OF SCIENTISTS AND ENGINEERS
ASE
NAVAL SEA SYSTEMS COMMAND

ACHIEVING TECHNICAL AND MANAGEMENT EXCELLENCE

THURSDAY, APRIL 11, 1991
SHERATON CRYSTAL CITY HOTEL
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Abstract: Contents: Where the SCN $ Go: An Affordability Focus; Systems Engineering in Ship Design: Where Do We Go from Here; Combat Systems Engineering Process; The Effects of Confined Water Operation on Ship Performance: A Guide for the Perplexed; Think Energy Again. Video Enhanced SECAT - An Energy Program; Quality Ship Service Power with an Integrated Diesel Electric Propulsion Plant; EMI - The Enemy Within; Damage Control: Last Line of Defense and Guardian of Sustained Mission Capability; Probabilistic Ship Structural Design; Forging the Future: Naval Shipyard Corporate Operations Strategy and Plan; Improving the Naval Ship Design, Acquisition and Construction Process; Is It SEAMOD Time; Hazardous Material and Hazardous Waste Management Within the Navy - The Time Has Come; Computer-Aided Acquisition and Logistics Management System: Making Logistics Easy for the Engineer; Why Engineers Don't Understand Logistics; Operational Use of Low Level White Lighting; FFG 61 Prototype Digital Technical Library.

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WHERE THE SCN $ GO: AN AFFORDABILITY FOCUS

John Johnston
Dineen O'Colman
and
Cathy Mathai
Cost Estimating and Analysis Division
(SEA 017)
Naval Sea Systems Command

April 11, 1991

Approved for Public Release
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ABSTRACT

The purpose of this paper is twofold: to show the trends in the availability of historical and planned Shipbuilding and Conversion, Navy (SCN) funds and to provide insight into major cost drivers of combatants. The SSN-21 and DDG-51 programs are examined in detail due to the large percentage of the budget represented by these programs. The cost drivers identified represent areas where cost reduction efforts of the future should focus.

The total amount and distribution by shiptype of SCN funds from Fiscal Year 1970 to Fiscal Year 1997 are examined as well as the historical and projected average unit costs of the attack submarines and major surface combatants. Following that, the costs of the attack submarines and major surface combatants are examined in detail in order to identify the areas of highest cost. Ship cost is categorized as either payload or platform and the cost drivers within these categories are identified. These costs are further separated into hardware and support costs in order to determine if support costs are an area to be considered for potential savings in future procurements.

FIGURES AND TABLES

ABBREVIATIONS

AUC	Average Unit Cost
CG	Guided Missile Cruiser
DDG	Guided Missile Destroyer
FY	Fiscal Year
GFE	Government Furnished Equipment
O&S	Operation and Support
RDT&EN	Research, Development, Test and Evaluation, Navy
SCN	Shipbuilding and Conversion, Navy
SSBN	Ballistic Missile Submarine, Nuclear
SSN	Attack Sub, Nuclear
SWBS	Ship Work Breakdown Structure
TOA	Total Obligational Authority
VLS	Vertical Launch System

OVERVIEW

All costs in this paper have been normalized to budget year 1990 dollars and represent planned SCN expenditures, not necessarily actual ship costs. The cost comparisons among attack submarines and major surface combatants do not attempt to quantify the cost impacts of changes in capability between ship classes or changes in ship size. RDT&E and O&S elements of life cycle costs are also not addressed.

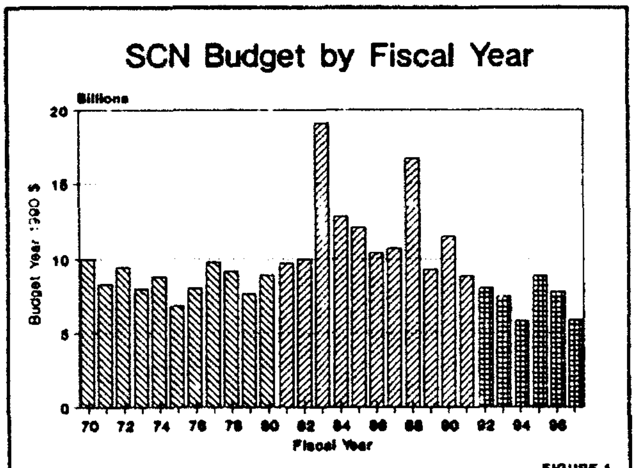

FIGURE 1

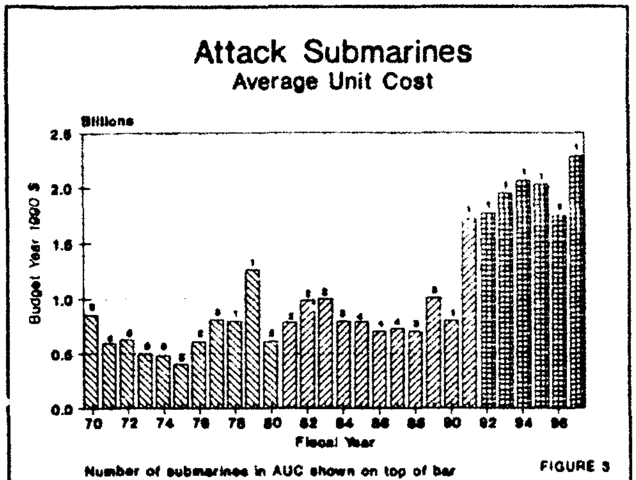

FIGURE 3

General SCN Trends

Currently planned SCN funding is at the lowest level in over twenty years. Between FY 1970 and FY 1980, the SCN plan averaged approximately $8.5 billion per fiscal year. The increase to an average SCN plan of $12 billion per fiscal year between FY 1981 and FY 1991 reflected the intensive build-up toward the proposed 600 ship Navy. The SCN plan for FY 1992 through FY 1997 projects average annual expenditures of approximately $7.3 billion, a six percent per year decrease, on average, from the FY 1981 through FY 1991 SCN plan. This trend is shown in Figure 1.

Average Unit Cost Trends

As shown on Figure 2, attack submarines and major combatants are projected to comprise approximately 82% of the total SCN plan (less aircraft carriers) available for ship construction between FY 1992 and FY 1997. While the SCN plan is decreasing, average unit costs of attack submarines and major combatants have been rising, as shown in Figures 3 and 4. While SSBN submarines are included in the SCN overview, they are not addressed in the following discussion of attack submarines because SSBN's are not included in the SCN plan after FY 1990.

The AUC of an attack submarine rose from $0.5 billion (SSN-688 class) in the mid 1970's to $1.7 billion in FY 1991 (SSN-21 class). This is an average cost increase of eight percent per year, excluding inflation impacts. Three significant upgrades and/or capability changes are included *in this increase* but are not separately quantified. The AUC of attack submarines (SSN-21 class) is projected to increase approximately five percent per year (excluding inflation) between FY 1991 and FY 1997, reaching $2.3 billion. However, this increase is driven largely by low rate production and capability changes.

The AUC of major surface combatants has also increased, though not as significantly. In the mid 1970's, the AUC of major surface combatants (destroyer and frigate mix) was $470 million. The AUC has increased approximately three percent per year, excluding inflation,

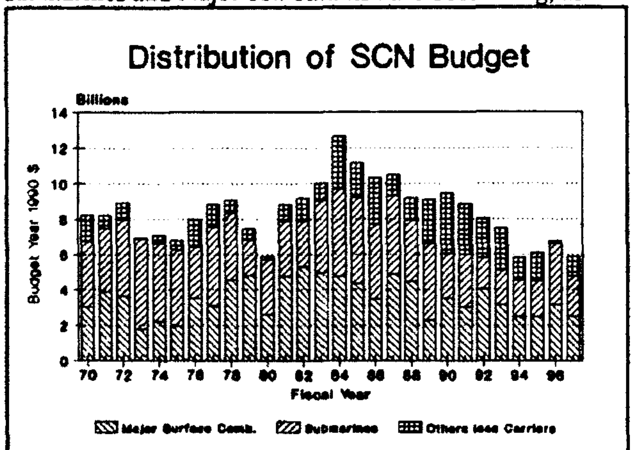

FIGURE 2

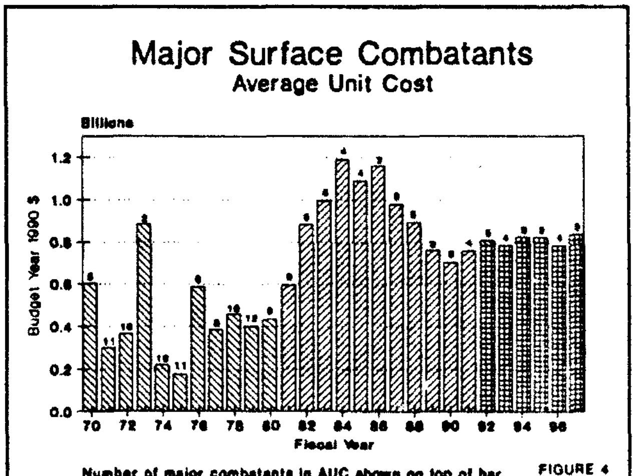

FIGURE 4

yielding an AUC of $760 million for FY 1991 DDG procurements. The trend is projected to continue, with the AUC increasing one and one-half percent per year between FY 1991 and FY 1997, reaching $840 million. As with the attack submarines, much of the cost increase is due to lower production rates and capability improvements.

The combination of decreasing SCN availability and increasing average unit costs has greatly impacted the buying power of the SCN plan. Between FY 1970 and FY 1980, the average buying power of the SCN plan was eight major surface combatants and three attack submarines per year. The average buying power of the projected FY 1992 through FY 1997 SCN plan has decreased to approximately three and one-half major surface combatants and one attack submarine per year. Also contributing to this reduction in buying power are changes in the shipbuilder/vendor business bases resulting from factors external to the scope of this paper (e.g. buy-out of other ship classes, decreasing availability of commercial work).

Given the decreased buying power of the SCN plan, attention must be directed to the programs within the SCN plan for potential areas of cost savings. Since attack submarines and major surface combatants are the largest portion of the SCN plan, these two programs will be examined for possible areas of cost reduction.

ATTACK SUBMARINES

The U.S. Navy's submarine force consists of attack submarines and ballistic missile submarines. Most hulls in operation today, and all planned procurements, are nuclear-powered. The submarine program has been a keystone of the Navy's maritime strategy since World War II. During the Reagan Administration, this plan was increased as part of the "600 Ship Navy" to a proposed fleet of 100 SSN's which resulted in a planned building rate of three to four hulls per year. Fiscal constraints have decreased the current building plan to approximately one attack submarine per year which will significantly reduce the planned SSN force.

The "Sturgeon" (SSN-637) class of nuclear submarines was procured from the early 1960's to the early 1970's and was the largest nuclear-powered ship class prior to the "Los Angeles" class. The "Los Angeles" (SSN-688) class was procured from the early 1970's until the award of the last hull in 1990. Since 1983, these hulls are known as the SSN-688I class because of major warfighting improvements such as the AN/BSY-1 integrated sonar/fire control system. The "Seawolf" (SSN-21) class is the next generation of fast attack nuclear submarines. The first of the class was awarded in 1989.

PLATFORM vs. PAYLOAD COST
SUBMARINE COMPARISON

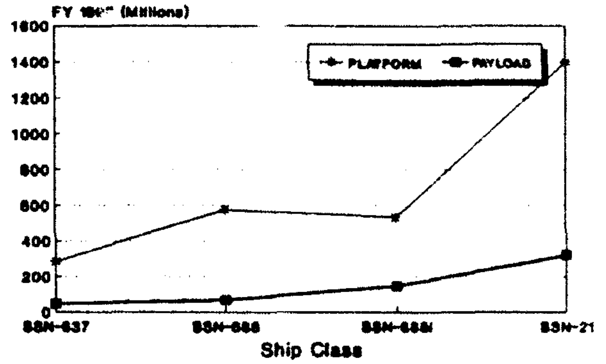

FIGURE 5

Submarine Cost Trends

The designs, capabilities, missions and costs of U.S. Navy submarines have varied over the past 30 years. Figure 5 shows the cost of an average follow ship in the SSN-637, SSN-688, SSN-688I and SSN-21 classes. All costs shown are for average follow ships in FY 1990 dollars. These costs have not been adjusted for differences in capabilities, quantity of ships, or amount of previous learning.

As shown in Figure 6, the payload cost approximately doubled as a percentage of total cost, increasing from 10% to 20% upon introduction of integrated combat systems such as the AN/BSY-1 and AN/BSY-2. AN/BSY-1 and AN/BSY-2 combine the sonar and fire control systems of the ship. The integrated combat systems provide improved capabilities such as enhanced weapon employment, command decision support, and contact management. The percentage of payload cost is slightly higher for the SSN-688I than the SSN-21 class because the SSN-

PLATFORM vs. PAYLOAD COST
SUBMARINE COMPARISON

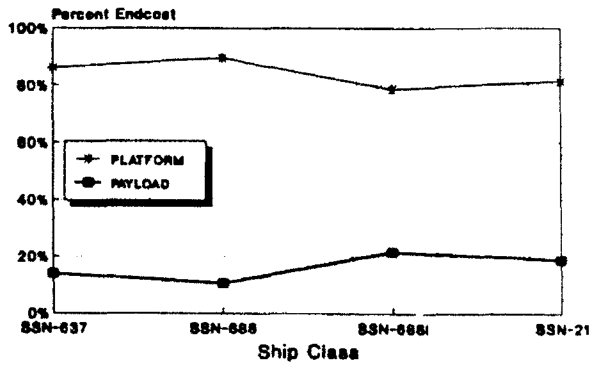

FIGURE 6

PLATFORM vs. PAYLOAD COST
SSN-688 CLASS HISTORY

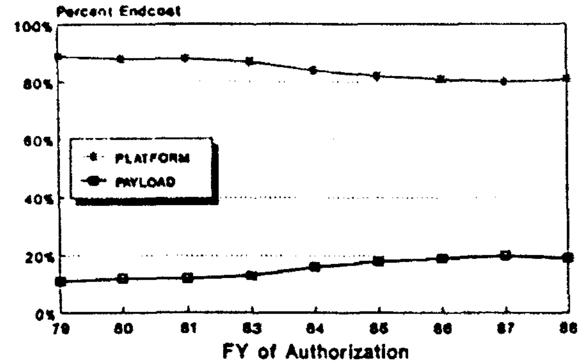

FIGURE 7

SSN-21 PLATFORM COST
SWBS BREAKDOWN BY PERCENT

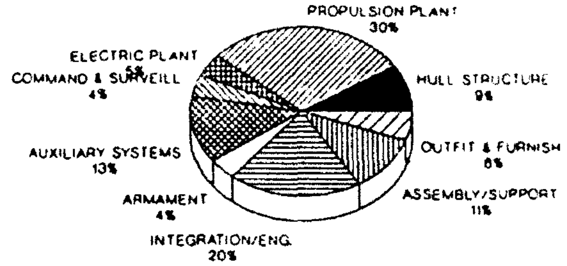

FIGURE 8

21 platform cost is.significantly higher than that of the SSN-688's.

Looking specifically at the "Los Angeles" Class, a clear trend can be seen from the FY 1979 SSN-688 to the FY 1988 SSN-688I. As a percentage of endcost, the platform decreases from 90% to 80% while the payload increases from 10% to 20%. Over this time span, the platform cost actually declines while the payload cost almost doubles. This shows that increases in ship's endcost may be directly attributed to the payload. Changes to the platform during production did not significantly impact cost.

As seen in Figure 5, the SSN-21 has a higher unit cost than the SSN-688I. Increased cost, however, must be weighed against capability. The SSN-21 has improved capabilities over the SSN-688I such as increased depth, speed, and silencing. It is also more heavily armed, more arctic capable and has an advanced combat system. A significant portion of the cost difference is also attributable to the reduction in business base during the SSN-21 procurement time frame as compared to that during the SSN-688I procurement time frame.

In order to know where to concentrate design efforts for future ship affordability, one must know what areas of ship construction are the cost drivers. These cost drivers must then be examined in detail to decide which new design areas will result in the largest cost savings.

"Seawolf" Class Cost Drivers

The SSN-21 is the only class of submarines currently in the Future Years Defense Plan (FYDP). Since it accounts for a large portion of the SCN plan, it is worthwhile to examine its breakdown of costs. Platform and payload costs will be examined separately to identify specific cost drivers for each part.

Platform

The estimated cost of an SSN-21 follow ship in FY 1993 is $1.7 billion assuming a build rate of approximately one ship per year. The ratio of platform to payload of an SSN-21 is 81% to 19%. A SWBS breakout of platform cost is given in Figure 8. Propulsion and auxiliary systems make up 43% of platform cost or 35% of endcost. These are the platform hardware cost drivers and should be considered the highest priorities for submarine hardware design affordability focus. Propulsion (SWBS Group 200) makes up 30% of platform cost or 24% of endcost and Auxiliary Systems (SWBS Group 500) make up 13% of platform cost or 11% of endcost.

Group 200 includes all nuclear and non-nuclear propulsion equipments with the leading cost drivers being the propulsor and the main propulsion complex. Other significant cost drivers in group 200 include shafting, steam piping systems, and radiation shielding.

The leading cost drivers within group 500 are the hydraulic fluid system, compressed air systems, steering and diving control systems, and drainage and ballasting systems. Other significant cost drivers in this group include special piping systems, and auxiliary fresh water cooling.

Approximately 31% of platform costs, or 25% of endcost, is non-hardware related. The majority of these costs are Integration/Engineering (SWBS Group 800) and Ship Assembly and Support Services (SWBS Group 900). Group 800 makes up 20% of platform cost or 16% of endcost. The most expensive items in this group are project management, engineering drawings, construction drawings, and quality assurance. Group 900 makes up 11% of platform cost or 9% of endcost. The cost drivers in this

SSN-21 PAYLOAD COST
ELECTRONICS COMPONENTS BY PERCENT

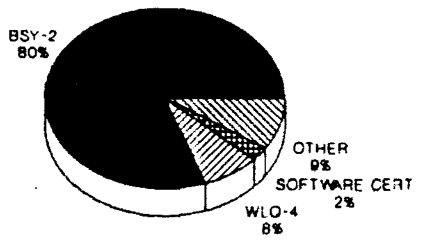

FIGURE 9

group include: tests and inspection, molds, templates, jigs, fixtures, and special tooling.

Payload

Figure 9 is a breakout of the major electronics payload components on an SSN-21 submarine. The AN/BSY-2 integrated combat system makes up 80% of the cost of payload or 15% of endcost. All other equipments are less than 10% of the cost of payload.

Ordnance is a very small part of payload on the SSN-21 consisting of the torpedo tubes and the ejection system. These items make up less then 2% of total endcost.

The hardware to support ratio of payload is 95% to 5%. This is primarily driven by the AN/BSY-2 ratio since it is such a large percentage of payload cost and has the same ratio. The amount of support shown for AN/BSY-2 may be misleading since a significant amount of AN/BSY-2 support is funded in RDT&EN (e.g. Navy Labs). The support percentage may also be understated because there are support costs buried in GFE hardware which could not be easily identified.

Findings

Given the trend and emphasis on more capable ships and the decreasing availability of SCN dollars, there should be greater emphasis in the future on affordability. A review of historical and projected submarine cost drivers shows that this effort needs to be concentrated in the hardware cost drivers (specifically propulsion and auxiliary systems), integrated combat system, and non-hardware cost drivers (specifically integration/engineering and ship assembly & support services).

If a new class of submarines was designed requiring a nuclear propulsion plant similar to that on the "Seawolf", an integrated combat system with capabilities such as AN/BSY-2 and similar auxiliary equipment, 48% of ship hardware cost would already be established before initiating a detailed design. If new, less expensive designs are not available for future submarine classes, requirements may have to be reduced in order to ensure that affordable, though less capable, ships are available for the fleet.

MAJOR SURFACE COMBATANTS

The U.S. Navy SCN account for surface combatants consists principally of aircraft carriers (CV's), battleships (BB's), cruisers (CG's), destroyers (DD's), frigates (FF's), and hydrofoil missile ships (PHM's). Nuclear propulsion variants of these ship classes include carriers (CVN's) and cruisers (CGN's). Another variation among the surface combatants is guided missile capability for anti-air warfare (AAW). Cruisers (CG's), destroyers (DDG's), and frigates (FFG's) are examples of guided missile combatants.

The CG-16, CG-26, CG-47, and DDG-51 classes are representative of U.S. Navy non-nuclear guided missile combatants authorized during the last three decades. Nine "Leahy" (CG-16) class cruisers, at 8,200 tons of full load displacement, were authorized between FY 1958 and FY 1959. These were followed by nine "Belknap" (CG-26) class cruisers, of roughly the same displacement, authorized in FY 1961 and FY 1962. The "Ticonderoga" (CG-47) class introduced the Aegis Weapon System to the fleet in 1983. A total of 27 CG-47's at 9,600 tons each were authorized between FY 1978 and FY 1988. To date, 17 "Arleigh Burke" (DDG-51) class Aegis Destroyers have been authorized with 22 more planned for FY 1992 through FY 1997. The DDG-51 class has a full load displacement of 8,300 tons which is similar to that of the CG-16 and CG-26 classes. This highly capable and survivable Aegis destroyer was designed to replace the retiring "Adams" (DDG-2) and "Coontz" (DDG-37) class guided missile destroyers. The lead ship is scheduled to be commissioned in FY 1991.

Surface Combatant Cost Trends

Figure 10 shows a comparison (in FY 1990 dollars) of platform and payload costs for specific, representative hulls of the CG-16, CG-26, CG-47, and DDG-51 ship classes. Each ship assessed represents a follow on procurement between units four and ten of production. The data in Figure 10 has not been normalized for differences in acquisition strategies or production learning. While the displacements of the CG-16, CG-26, and DDG-51 classes are comparable, their costs vary. Survivability improvements, such as detection signature reduction initiatives and environmental protection systems, also affect the cost of the platform.

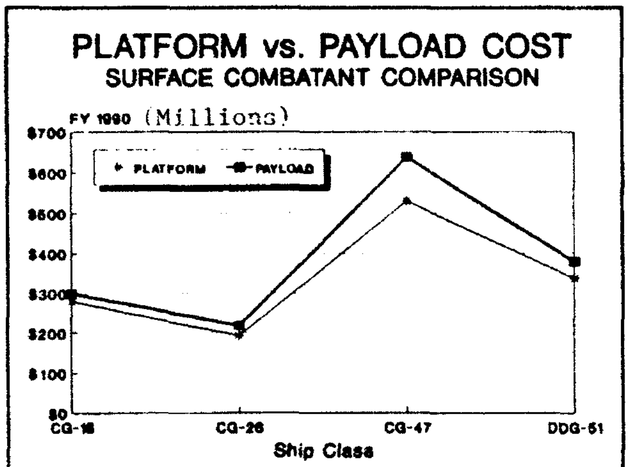

FIGURE 10

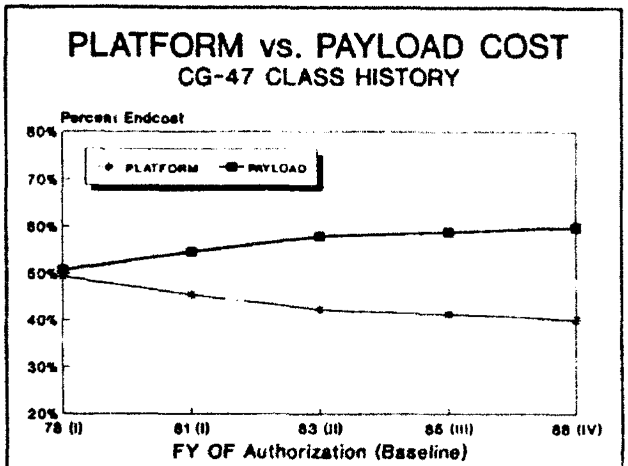

FIGURE 12

As shown in Figure 11, the payload and platform elemental costs of surface combatants remain approximately the same percentage of total cost across all ship classes assessed. The payload cost of these ships accounts for a slightly larger share (52% - 55%) of endcost than the platform. Payload is determined by the combat systems necessary to meet the warfare mission requirements of the ship. These combat systems in turn determine the amount of ship support services to be provided by the platform. For instance, sophisticated combat systems often influence the power, climate control, and other shipboard service demands on the platform as well as its size. This helps to explain the virtually constant platform versus payload percentages seen in Figure 11 despite the significant differences in unit costs and level of combat system sophistication between the ship classes.

An analysis of the CG-47 class shows that the payload cost increases as a percentage of total cost over the ship class production. While the platform configuration remains relatively unchanged, allowing cost improvement due to production repetition, the combat system is upgraded during the production program which negates some of the savings associated with learning curve theory. These upgrades are phased into the configuration baseline as they become available and the production program matures. For instance, the CG-47 class consists of four major baseline configurations. Baseline I is the initial CG-47 design. This was followed by Baseline II (beginning with CG-52) which incorporated the Vertical Launching System (VLS) and Tomahawk missile capability. The AEGIS radar SPY-1A was upgraded to SPY-1B in Baseline III (beginning with CG-59) and Baseline IV (beginning with CG-65) upgraded the computer systems from UYK-7 and UYK-20's to UYK-43 and UYK-44's. As shown in Figure 12, each upgrade increases the payload share of endcost.

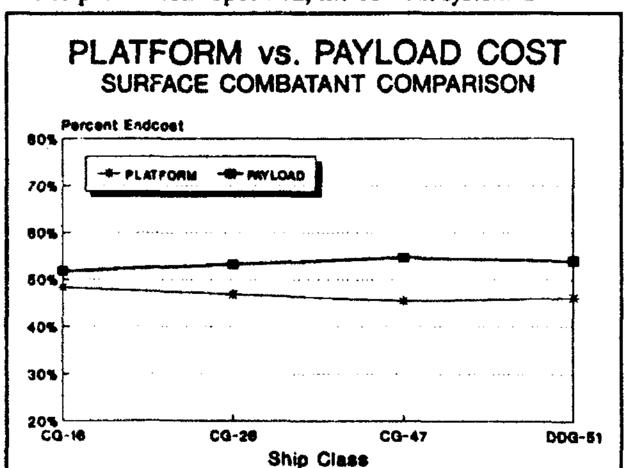

FIGURE 11

Modified repeat design approaches allow the Navy to incorporate warfighting improvements without the level of non-recurring costs associated with the lead ship of a new class. A modified repeat approach to shipbuilding utilizes an existing ship design and redesigns only those areas necessary to incorporate upgrades. This approach maximizes commonality and allows baseline upgrades to be phased in over time without introducing entirely new ship designs.

In order to constrain combatant costs, an identification of cost drivers will help to focus attention on areas to target for cost reduction opportunity.

"Arleigh Burke" Class Cost Drivers

The DDG-51 shipbuilding program is the only major surface combatant currently planned for in the Future Years Defense Plan (FYDP). DDG-51 class destroyers account for 46% of the planned new construction shipbuilding budget (less aircraft carriers) for FY 1992 through FY 1997. Since DDG-51 accounts for such a large percent-

DDG-51 PLATFORM COST
SWBS BREAKDOWN BY PERCENT

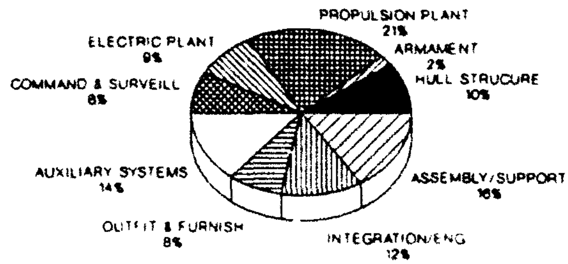

FIGURE 13

age of the planned SCN budget, it is important to further investigate and identify potential cost drivers.

Platform

The platform cost portion of the DDG-51 accounts for 46% of endcost. Figure 13 provides a breakdown of DDG-51 costs by SWBS. Costs can be further categorized as hardware or non-hardware. Major platform hardware costs for the DDG-51 include the propulsion plant and auxiliary systems.

As illustrated, the Propulsion Plant (SWBS Group 200) accounts for the largest share of platform cost at 21% or 10% of endcost. The propulsion plant is the most expensive element of the shipbuilder basic construction cost for the DDG-51, primarily consisting of material costs for reduction gears & propulsor systems. Gas turbines, reduction gears, combustion air systems, and propulsion shafting are among the cost drivers.

Auxiliary Systems (SWBS Group 500) accounts for 14% of the DDG-51's platform or 6% of endcost. The cost of the firemain & flushing (sea water) system, compressed air systems, ventilation system, and refrigeration system are the most expensive within this group. Other items of notable cost are the ship fuel & compensating system and the steering & diving control system.

Nearly 30% of the platform cost is essentially non-hardware costs for shipbuilder Integration/Engineering (SWBS Group 800) and Ship Assembly & Support Services (SWBS Group 900). Group 800 cost drivers include: project management, planning and production control, construction drawings, and tests & inspection. Cost drivers within group 900 include: construction support, material handling & removal, trials, molds & templates, and tests and inspection.

Group 800 and group 900 costs are a function of shiptype, specification requirements, and shipyard construction practices. These costs are significantly higher for the lead ship of a class where considerable engineering design and rework is incurred, but decrease for subsequent production builds as the configuration baseline and shipbuilding processes begin to stabilize. Group 800 and 900, as a percent of the production cost associated with groups 100 through 700, historically have proven to be fairly consistent at a given shipyard.

Hull Structure (SWBS Group 100) accounts for only 10% of the platform cost or less than 5% of the endcost. This is, however, the most labor intensive SWBS group, with the exception of ship assembly & support services, in terms of shipbuilder production cost. Manhours associated with group 100 comprise roughly 17% of total ship production hours.

Payload

Payload cost accounts for slightly more than half (54%) of the ship's endcost. This is consistent with platform to payload ratios observed on prior major combatant ship classes. During DDG-51 class production, it is likely that combat system capability will continue to evolve to meet the threat. Based on the production history of the CG-47 class, the payload percentage of DDG-51 endcost will likely increase in the future as these performance upgrades are incorporated into the fleet.

DDG-51 payload cost consists of roughly two-thirds ordnance and one-third electronics GFE. Ordnance payload equipment accounts for approximately 65% of payload or 35% of total ship endcost. Illustrated in Figure 14, the Aegis Weapon System comprises 59% of that ordnance amount or 21% of endcost. Other elements of ordnance payload include the VLS, Harpoon/Tomahawk missile systems, 5" gun and others.

DDG-51 PAYLOAD COST
ORDNANCE COMPONENTS BY PERCENT

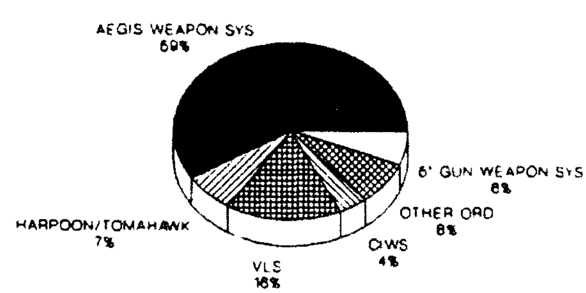

FIGURE 14

DDG-51 PAYLOAD COST
ELECTRONICS COMPONENTS BY PERCENT

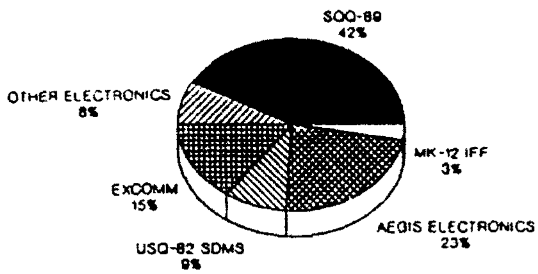

FIGURE 15

The electronics equipment comprises 35% of payload or 19% of endcost. As sho..n in Figure 15, the largest elements are the SQQ-89 sonar system and the government furnished computers, displays, and tubes associated with the Aegis Weapon System. The SQQ-89 accounts for 42% of electronics payload or 8% of endcost while Aegis GFE accounts for 23% of electronics or 4% of endcost. Other elements of electronics payload include exterior communications and the shipboard data multiplex system.

More than 30% of the payload cost, or 16% of the total ship endcost is for engineering services, system integration, test and evaluation (T&E), and program support. This percentage may be understated in this analysis since Government Furnished Equipment (GFE) items such as Navy standard computers and displays are included as payload hardware costs, thus including engineering, integration, T&E and program support costs associated with these items as hardware costs.

As combat systems become more complex, integration and testing requirements will increase. Facilities and personnel required for these efforts must be maintained at a critical level from year to year. The 16% engineering services to endcost ratio cited above is based on a buy of five systems a year. Less than four ships per year are currently planned for FY92 through FY97. This combination of increasingly complex combat systems and smaller buys will likely increase the engineering services to endcost ratio in the future.

Findings

The cost of the payload placed aboard surface combatant platforms comprises the majority of the ship's endcost. Payload as a percentage of endcost historically increases over time as the combat system is upgraded. For the DDG-51 class, the platform hardware cost drivers are found in the propulsion plant and auxiliary systems. Approximately 30% of platform costs are attributable to integration/engineering and ship assembly & support services. Likewise, roughly 30% of payload costs cover engineering services, system integration, T&E, and program support. These efforts are likely to increase as a percentage of ship endcost as fewer units are procured each year. Similarly, these efforts would likely increase as a percentage of endcost should future baseline upgrades be required.

CONCLUSION

The amount of money available for new ship construction is declining. This equates to a loss of buying power for the U.S. Navy. In addition, average unit costs are on the rise as we build more capable and survivable warships. To continue upgrade capability in this austere fiscal environment will require increased emphasis on affordability. These efforts should focus on the areas of highest potential payback such as the integrated combat systems and the support infrastructure associated with combat system production. Other areas to focus affordability efforts upon include combatant propulsion plants and auxiliary systems.

References

Jane's Publishing Company, Ltd. Jane's Fighting Ships: 1986-1987. London, England: Jane's Publishing Inc., 1987.

Jane's Publishing Company, Ltd. Jane's Fighting Ships: 1987-1988. London, England: Jane's Publishing Inc., 1988.

NATO. "Allied Naval Engineering Publication on Ship Costing - Draft". November 1990. UNCLASSIFIED.

NAVSEA. "NAVSEA 4280/2A: Unit Price Analysis - Summary": August 1978. UNCLASSIFIED.

NAVSEA 017. "NAVSEA Ship Cost Estimating: A Reference Document for the Entry-Level Ship Cost Estimator". Crystal City, VA: September 1986. UNCLASSIFIED.

Polar, Norman. The Ships and Aircraft of the U.S. Fleet - Fourteenth Edition. U.S. Naval Institute, Annapolis, MD: 1987.

Appendix A

Glossary of Terms

PLATFORM: SWBS groups 100, 200, 300, 500, 600, group 700 handling and stowage equipment, and the installation and integration costs for groups 400 and 700 equipment.

PAYLOAD: Electronic (SWBS Group 400) and ordnance (SWBS Group 700) equipment costs excluding: handling and stowage equipment, installation and integration, aircraft and expendable ordnance.

ENDCOST: All expected costs, including inflation, through the ship delivery period with the exception of post-delivery and outfitting. This includes the following costs:

> **PLANS:** Detailed design costs, including related engineering calculations, computer programs, contractor responsible technical manuals, damage control books, ship's selected records, and mock-ups.
>
> **BASIC CONSTRUCTION:** All allowable labor, overhead, and material costs, including the installation of shipbuilder installed government furnished material, shipbuilder profit and cost of money.
>
> **CHANGE ORDERS:** Allowance for future Headquarters Modification Requests (HMRs) and Field Modification Requests (FMRs).
>
> **GFE:** Government Furnished Equipment - furnished to the shipbuilder at no cost to the shipbuilder, generally shipbuilder installed. Includes Electronics, Ordnance (i.e. payload) and Hull/Mechanical/Electrical (part of platform).
>
> **ESCALATION:** Money allocated to compensate for labor and material inflation over the period of the ship construction contract.

SWBS: Ship Work Breakdown Structure: Categorizes ship construction costs into technical sub-groups (SWBS 100-700), engineering (SWBS 800) and construction support (SWBS 900).

SWBS GROUP 100: Hull Structure: Includes shell plating, decks, bulkheads, framing, superstructure, pressure hulls, and foundations.

SWBS GROUP 200: Propulsion Plant: Includes boilers, electric/hydraulic motors, reactors, turbines, engines, gears, shafting, propellers, steam piping, lube oil piping, and radiation shielding.

SWBS GROUP 300: Electric Plant: Includes ship service power generation equipment, power cable, lighting systems, and emergency electrical power systems.

SWBS GROUP 400: Command and Surveillance: Includes navigation systems, interior communications systems, fire control systems, radars, sonars, radios, teletype equipment, telephones, command and control systems, and countermeasures.

SWBS GROUP 500: Auxiliary Systems: Includes air conditioning, ventilation,refrigeration, replenishment-at-sea systems, anchor handling, elevators, fire extinguishing systems, distilling plants, cargo piping, steering systems, and aircraft launch and recovery systems.

SWBS GROUP 600: Outfit and Furnishings: Includes hull fittings, painting, insulation, berthing, sanitary spaces, offices, medical spaces, ladders, storerooms, laundry, and workshops.

SWBS GROUP 700: Armament: Includes guns, missile launchers, ammunition handling and stowage, torpedo tubes, depth charges, mine handling and stowage, and small arms.

SWBS GROUP 800: Integration/Engineering: Includes drawings, design support, quality assurance, ILS, reliability & maintainability, project management, and all other engineering effort.

SWBS GROUP 900: Ship Assembly & Support Services: Includes molds; staging, scaffolding & cribbing; launching; trials; temporary utilities and services; materials handling and removal; and cleaning services.

TOA: Total Obligational Authority: The total amount available in the budget for any given year. Includes ship endcost, any additions for advanced procurement for future years and any subtractions for advanced procurement from prior years.

SYSTEMS ENGINEERING IN SHIP DESIGN: WHERE DO WE GO FROM HERE?

Howard Fireman
Senior Project Coordinator
Hull Engineering Management Office
(SEA 55D6)
Naval Sea Systems Command

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The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor of the Department of the Navy

Abstract

The term "Systems Engineering" and total ship engineering are new "fad" words being used recently in the ship design business. There is no argument that the application of systems engineering principles and its tools are critical to a successful ship design. Then why is it so difficult for naval engineers at NAVSEA to execute naval ship designs according to this principle? How good is the current process? Is ship design getting harder? This paper presents an introduction to the systems engineering process, a case study of the Common Hull SWATH ship design, application of systems engineering to this design, and recommendations for future ship designs.

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ABS	American Bureau of Shipping
APM	Assistant Program Manager
CFR	Code of Federal Regulations
CNO	Chief of Naval Operations
DIM	Design Integration Manager
DSDM	Deputy Ship Design Manager
DTRC	David Taylor Research Center
HVAC	Heating, Ventilation, and Air Conditioning
ICD	Interface Control Documents
INSURV	Navy Board of Inspection and Survey
MOE	Measures of Effectiveness
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
MEL	Master Equipment List
MSC	Military Sealift Command
OR	Operational Requirement
PMS	Program Manager Ship
PNA	Project Naval Architect
RMA	Reliability, Maintainability, Availability
RPM	Revolutions per Minute
R&D	Research and Development
SCIB	Ship Characteristics Improvement Board
SCN	Ship Construction Navy
SDM	Ship Design Manager
SE	Systems Engineering
SOW	Statements of Work
SPAWAR	Naval Space and Warfare Command
SS	Sea State
SUPSHIP	Supervisor of Shipbuilding, Conversion and Repair
SURTASS	Surveillance Towed Array Sensor System
SWATH	Small Waterplane Area Twin Hull
T-AGOS	Auxiliary General Ocean Surveillance MSC Manned
T-AGS (O)	Auxiliary General Ocean Survey MSC Manned
TGM	Task Group Manager
TLR	Top Level Requirements

INTRODUCTION

The naval ship design and construction process is complex and difficult to manage. During the process, the design team is faced with problems that have many constraints and solutions that are hard to find. On many occasions, ship designs have had collocated ship design sites. The purpose

of these teams is to provide the best environment where the ship design technical staff can work together to produce an integrated ship design product. These collocated teams attempt to have a majority of the technical staffs located on site. Even with this collocated environment during preliminary and contract design, the government is adjudicating numerous changes during the detail design and construction process. On complex ships (combatants), the number of changes have exceeded one thousand.

There are several possible explanations for the magnitude of changes: poor subsystem definition, incomplete attempt at systems engineering, design modifications required by mandated system upgrades from the CNO sponsor, ship system safety items, specification deficiencies, producibility, etc. This paper will concentrate in the area of systems engineering. This paper will provide an introduction to systems engineering, review the Common Hull SWATH acquisition program as a case study, and provide system engineering recommendations for future naval ship designs.

WHY DO WE NEED SYSTEMS ENGINEERING?

Systems Engineering is necessary for successful development of modern, complex, and multi-disciplined ship systems. In today's environment, the ship designers are faced with many divergent system constraints and requirements. They include lightest weight, higher system performance, acceptable risks, most producible, lowest acquisition cost, tendency towards subsystem optimization, lowest operational and maintenance cost, lowest risk, utilization of most modern technology, minimum manning, highest degree of automation, non-developmental items, etc. These design attributes is what makes systems engineering a tough job. In order to balance all of these competing needs the use of systems engineering and its tool box is required.

WHAT IS SYSTEMS ENGINEERING?

The participants in a complex ship design typically enter the program with a bias towards their specific design specialization displayed in figure 1. In order to find solutions, the ship system managers (Ship Design Manager, Project Naval Architect, Design Integration Manager, Task Group Managers, and Program Manager (APM)) must view the system (the ship) from the outside. Systems Engineering as

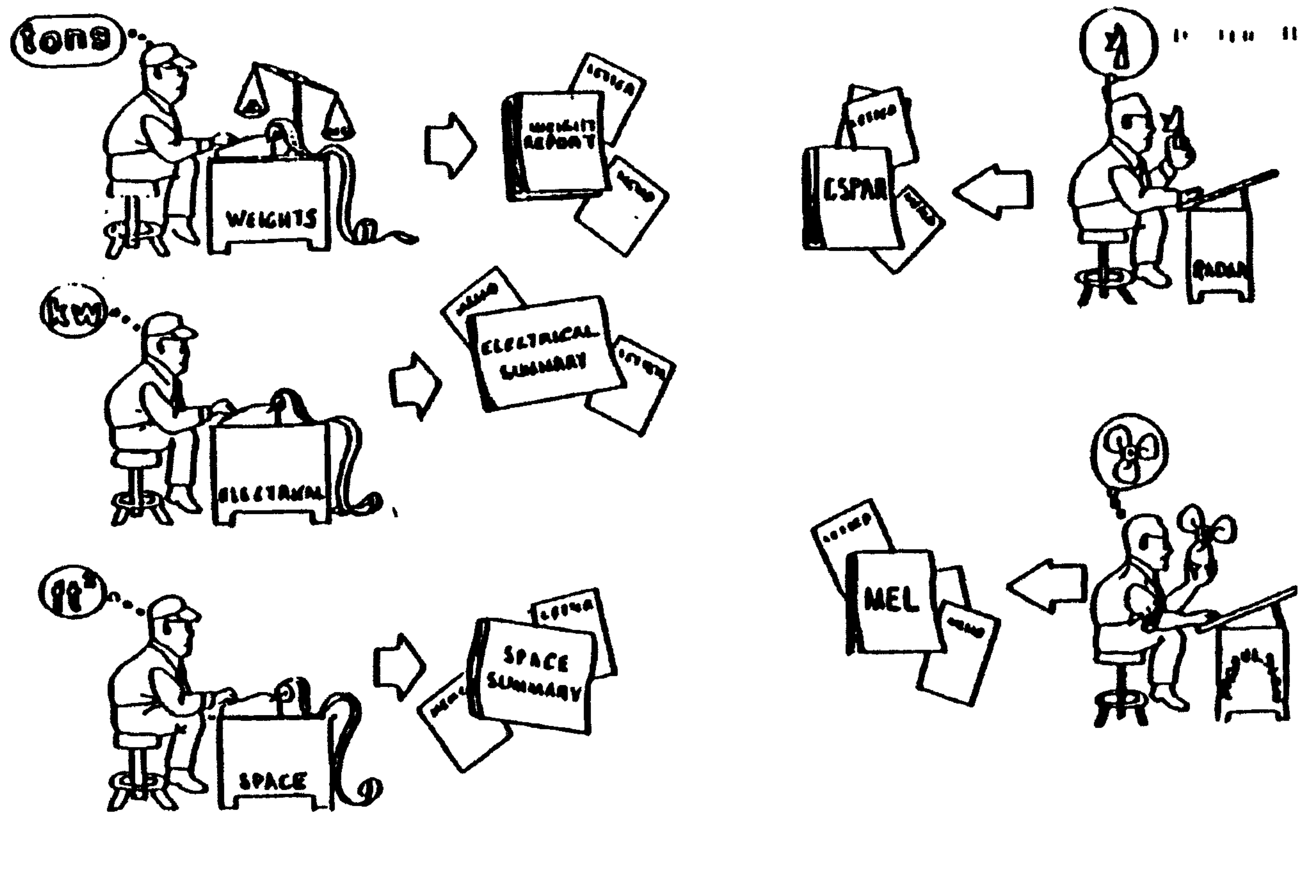


FIGURE 1 - SHIP DESIGN PERSPECTIVES

1

part of ship design management must not be treated as another management/engineering speciality. This is true since systems engineering is involved in and affects outputs of all technical specialties. The utilization of systems engineering must be directed from the ship design managers office. It must be employed as an additional discipline of ship design management. The ship design management elements are shown in figure 2.

In the existing NAVSEA ship design process, these functions are jointly performed by the Ship Design Manager, PNA/DIM, and the various Task Group Managers. System Engineers have a diverse set of job functions. Their activity varies from elements of program and technical management. Specifically, the functions of ship systems engineers include:

- System Integration. The includes establishing interface control documents between ship platform and mission systems, evaluating total system performance based on top level requirements, detailing technical data flow between ship subsystems, and developing System Documentation.

- Technical Coordination. This includes problem solving within a specific design discipline and resolving issues between subsystems. The system engineer must find the "good enough" design solutions and prevent technical disciplines from sub-optimization.

- Technical Guidelines. This includes the guidelines to the design group technical areas. The system engineers must transmit the technical approach, project objectives, project philosophy, and provide clear definition of the sponsors requirements.

- Sponsor Interaction. This includes frequent communication with the NAVSEA Program Managers (PMS), participation in Ship Characteristic Improvement Board (SCIB) meetings, and interaction with the fleet operators. The system engineers communications must cover all technical and management elements of the program.

- Task Definition. This includes joint preparation of the task statements of work (SOW), task deliverables, task schedules, and scheduling integration of all tasks, and critical path analysis with the design task leaders.

<u>SHIP DESIGN AND ACQUISITION MANAGEMENT</u>

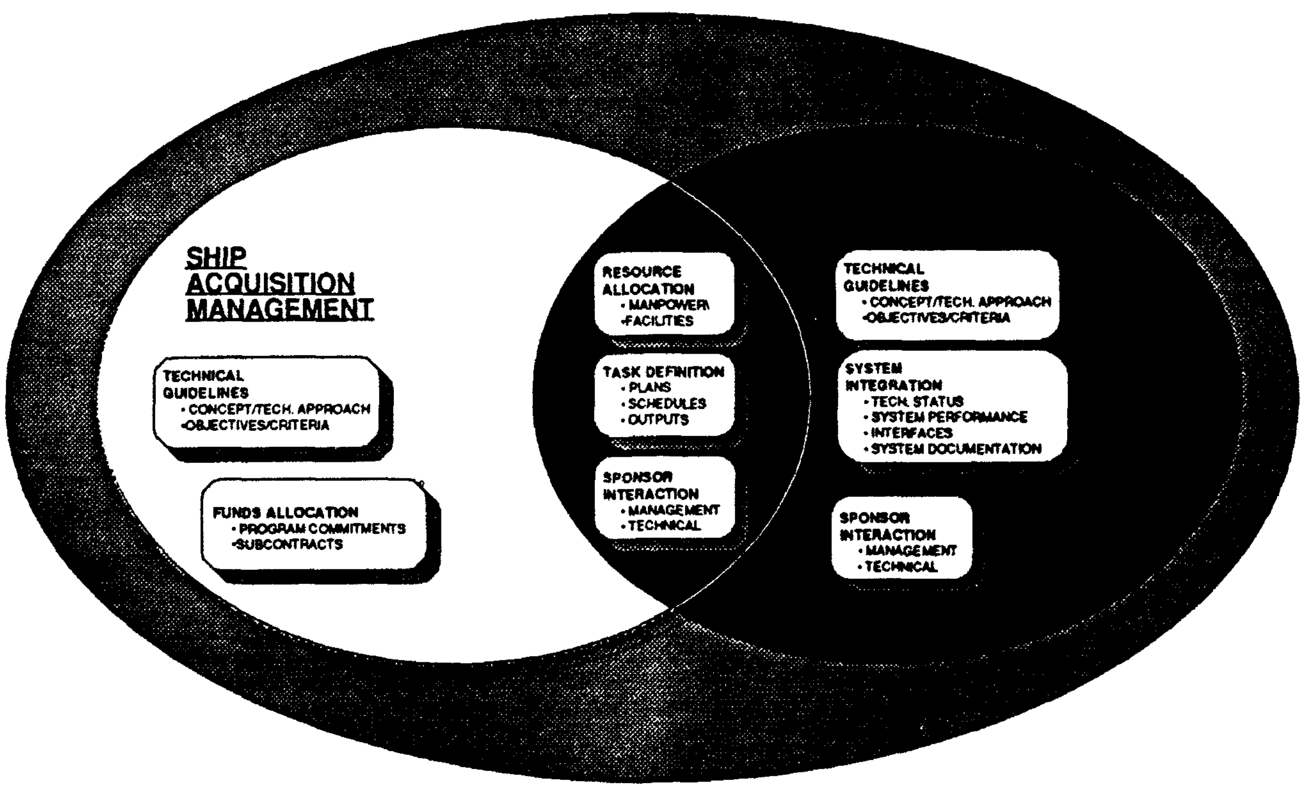


FIGURE 2 - SHIP DESIGN MANAGEMENT FUNCTIONS

- Resource allocation. This includes allocation of required manpower, arrangement of special facilities for design and testing, and allocation of design money to the design specialists.

WHAT IS A GOOD TOTAL SHIP SYSTEM?

Most importantly, a good system must meet the sponsor's (user's) need. It must interface with and complement the operation of related systems. For example the ship platform must be **compatible** with the ships mission systems. The system must also function over the real range of imposed, environmental and operating constraints. For example, the ship and all mission systems be operational thru sea state 6. Finally, the system should be capable of adapting to future change during the ships 30 year life. Future change may include new weapon systems, communications, aviation support, ship support, etc.

HOW GOOD IS GOOD ENOUGH?

The practice of Systems Engineering must aim the design team for the adequate vs. the ideal performance. System Engineering (S.E.) is not a science but it is the art of **"good enough"**. The art of "good enough" is a deviation from the classical ship design process. Total ship optimization could occur if the project had an unlimited amount of time and resources. A total ship design is not necessarily the sum of the individual system solutions arrived at independently. Ship design is difficult and finding a solution to the many variables, constraints, and complexity of the ship platform and mission systems is **"good enough"**.

A total system solution cannot allow one subsystem to be optimized at the expense of the total ship solution. We need S.E. to minimize the chances of the entire effort being a disaster. The utilization of S.E. must provide the flexibility and growth to include future "unknown-unknown" requirements to the system by utilization of ship service life allowance. Finally, S.E. should only push the state-of-the-art in areas where the payback to the system is worth the risk being taken.

THE SYSTEM VIEWPOINT

System Engineers in NAVSEA ship design are typically the Task Group Manager, PNA, Design Integration Manager, and the Ship Design Manager. They must have a system (i.e., total ship) viewpoint. These individuals view the system from the **outside**. The system engineers are concerned with the effect of all system elements as they effect overall system design, performance, risk, cost, and schedule. Systems Engineering provides the technical **"glue"** which makes separate design disciplines and subsystems function together to provide an integrated system which performs the specified top level requirements.

System engineers must have a working knowledge of all areas which effect the performance of the total system. However, they are not intimate with the day to day details all technical areas. The Systems Engineer is directly responsible for identifying, coordinating and implementing the technical compromises between design disciplines (SEA 55, SEA 56, SEA 06, SEA 50, SPAWAR, NAVAIR, etc.) and other organizational components (PMSs, CNO sponsors, INSURV, etc.).

On the other hand, the classical **"Design Engineer"** (NAVSEA task leader) has a specialist's or technical viewpoint. This individual typically has a more narrow ship perspective and views the system from the **inside**. They must be concerned with the effect which other system elements have on his/her specific design task and not typically how his/her area affects others. Many design disciplines have a total ship viewpoint in performance of their job. Some of these design disciplines include ship arrangements, systems safety, human engineering, etc.

THE SYSTEMS ENGINEERING APPROACH/PROCESS

The systems engineering approach is similar for every project. The approach is top down. The process mandates that system needs be established before the system requirements are defined. For example, first define why a T-AGOS ship is needed. Then establish system requirements such as speed, endurance, sea state performance, operational environment, etc. Last determine how that ship which has the given needs can satisfy the stated requirements. This approach prohibits "Solutions looking for a problem". In summary, how the system will accomplish its job cannot be done until first the needs analysis and then the requirements definition are both completed. This approach is displayed in figure 3.

The process incorporates the necessary iterative loop between design solutions and requirements to achieve practical solutions. In the ship design process this iterative aspect is tackled initially during the feasibility studies and the preliminary design. However, many design and acquisition requirement issues are addressed during the later design stages.

NAVSEA SHIP DESIGN STATUS

The current NAVSEA design process works in the existing organizational context. Producing a high quality systems integrated product is getting harder because mission and ship support systems are getting more complex, system acquisition costs are too high, ship design funds are diminishing,

SYSTEM ENGINEERING APPROACH

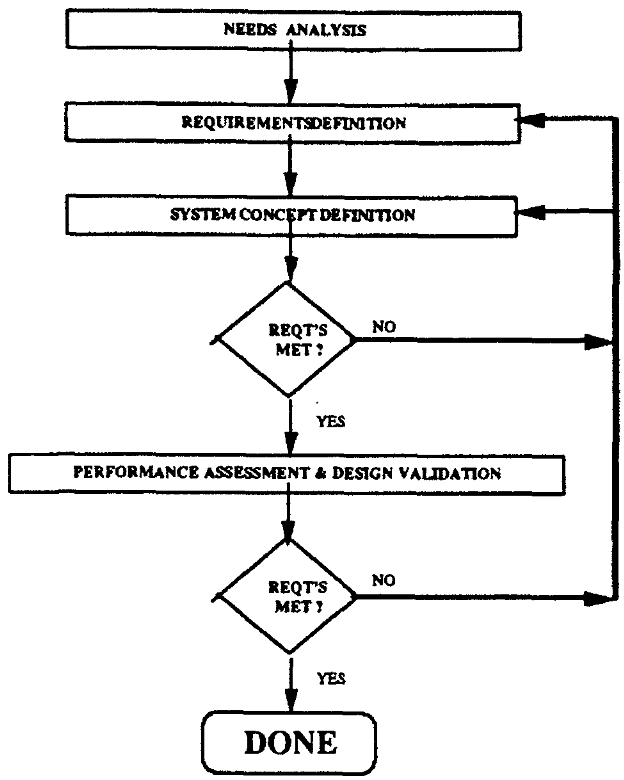


FIGURE 3

and the ship designers are faced with more and more constraints. The present day naval engineer is hampered because systems engineering (Level I) tools (for preliminary and contract design) have not kept pace with the advancements of mission and ship support systems. The complexity of the systems and the ship systems engineering process is making ship design harder. In many cases, the ship designers have no choice but to work harder and not smarter.

COMMON HULL SWATH SHIP DESIGN

The U.S. Navy recently completed the contract design of the worlds largest SWATH (Small Waterplane Area Twin Hull) ship, the T-AGOS 23, shown in figure 4. This unique hull form and major ship systems has been applied to two ship missions. The first ship class is the T-AGOS 23. The second ship class is the T-AGS (OCEAN). The T-AGOS 23 is being designed to collect, process, and transmit acoustic data in support of ocean surveillance requirements.

The T-AGS (OCEAN) is being designed to provide the Naval Oceanographer the capability to collect oceanographic data.

The SWATH hull form was selected to provide high sea state performance of the ship systems, personnel, and mission systems. This SWATH concept offers significant operational capability in sea state 6 and 7. Current Navy assets offer a similar mission capability in sea states 4 and 5.

The Common Hull SWATH program presented numerous challenges to the ship design team. The final acquisition strategy required that these two vessels, to the maximum extent practical, share the R&D costs necessary for design. This business decision required that performance requirements be adjusted to meet the overall acquisition requirements. The decision to proceed with the Common Hull Program SWATH program, in fact, is an attempt to let systems engineering create the solution. The resulting hull configuration is a compromise which supports both missions. The respective missions of the two ships are not mutually compatible for one ship design effort. However, the naval ship designers were successful in achieving the desired design goals. The result is probably not the best design solution for either ship were it designed from scratch. However, the design solution is **"good enough"**. A summary of the ship design performance requirements and characteristics is displayed in Table 1 for T-AGOS 23 and T-AGS (OCEAN), respectively.

Later in this paper, specific ship design areas will be examined as they relate to the principles of systems engineering.

A CASE STUDY

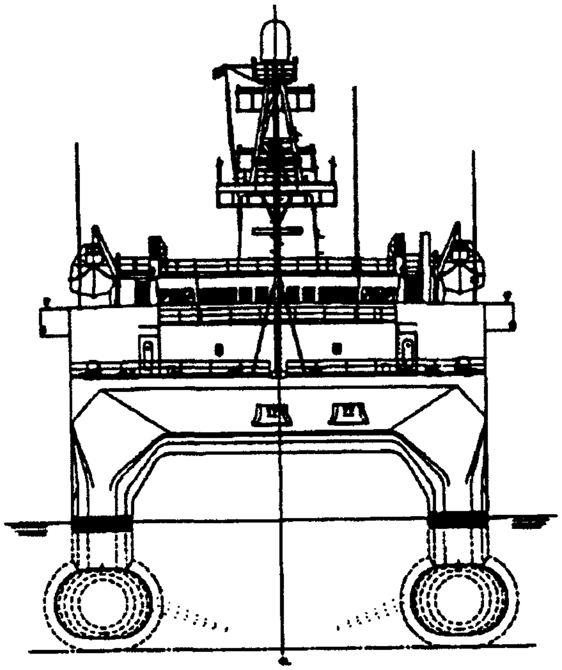
COMMON HULL SWATH DESIGN: AREAS OF DIFFICULTY

Typically, subsystems are developed independently of their ultimate ship platform. This fact and several other high level issues hamper the systems engineering process. These issues are discussed below in relation to the Common Hull SWATH case study example.

Table 2 lists design system interface areas pertinent to the Common Hull SWATH ship design. These areas were evaluated based on their overall system engineering effectiveness during the T-AGS (OCEAN) and T-AGOS 23 designs. The scoring process was subjective. The scoring was not meant to be critical of the design team but rather of the process.

A discussion of the specifics of the scoring will not be done. However, a general conclusion from the information in Table 2 is clear. The performance of the design team was

hampered by several high level problems in the systems engineering process. They include:



1- Development of ORs/TLRs and Subsequent Subsystem Requirements.

2- Development of design tools.

3- Availability of the design team.

4- Reasonableness of the des'gn schedule and resources.

5- Ability to make decisions.

Development of ORs/TLRs and Subsequent Subsystem Requirements

The most significant reason for less than ideal performance, on the Common Hull SWATH program, is the **requirements definition**. If the requirements are unclear, unintegrated, unrealistic, conflict, misunderstood at the beginning of the feasibility study, the design is in for a rough ride. The entire design revolves around these requirements. In order to converge, downstream in the design, the design team will have to work hard to find that solution the is "good enough". Both the T-AGS (OCEAN) and the T-AGOS 23 had difficulties in this area which hurt the overall process.

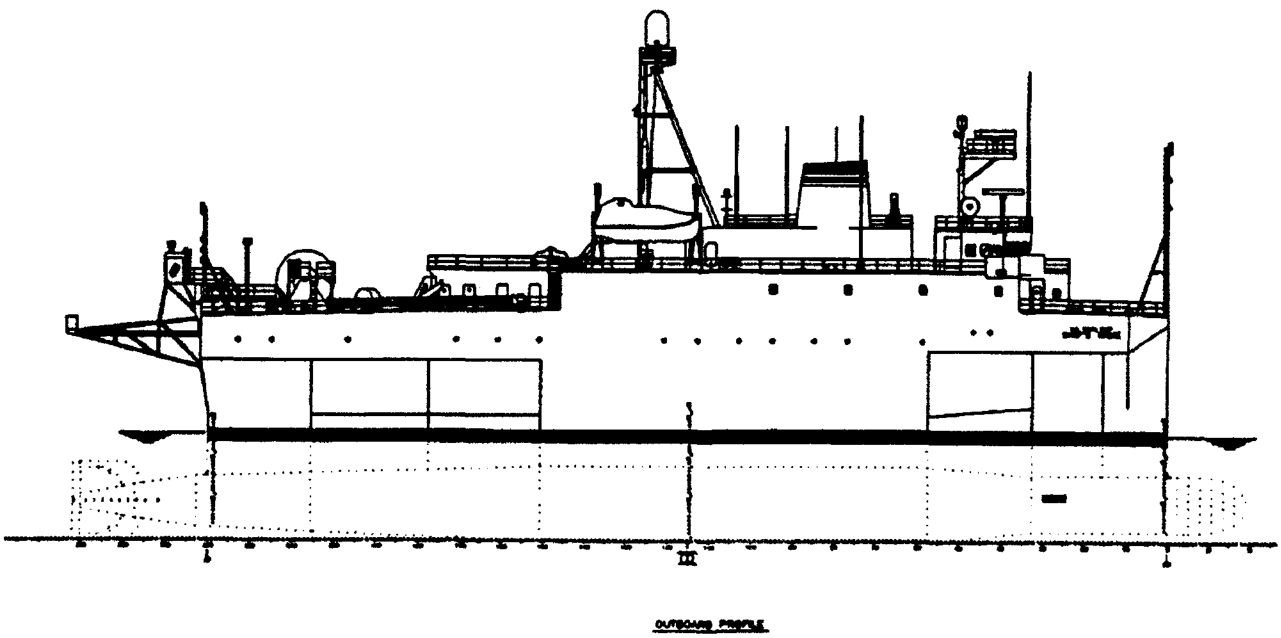


Figure 4

TABLE 1		
SUMMARY OF COMMON HULL SWATH REQUIREMENTS		
	HULL	
PERFORMANCE REQUIREMENTS	T-AGOS 23 CONTRACT DESIGN Ocean Surveillance	T-AGS(O) PRELIMINARY DESIGN Oceanographic Research
Sustained Speed	12.0 kts	12.0 kts
Endurance Speed	10.0 kts	10.0 kts
Range	3000 nm @ 10 kts 60 Days @ 3 kts	8500 nm @ 12 kts 25 days @ 3 kts 3 Days Reserve
Mission Duration	73 days total	53 days total
Seakeeping	Towing (@3 kts) - SS6 all Heading - SS7 Best Hdg SURTASS Handling - SS6 Following sea +/- 1 knot - SS7 is goal Second System - SS6 Best Hdg	Towing - SS5, 2.5 kts, 25,000 lbs - SS5, 6.0 kts, 10,000 lbs Stationkeeping - 150 ft circle SS5 Trackline - 150 ft either side, 1-6 kts, all towing conditions
Survival	Above SS 8	SS 9
Mission Systems	SURTASS Second Acoustic System	Seismic Bathymetry Water Column Acoustic
ACCOMMODATIONS		
MSC Ships Force	22	25
Mission Personnel	19	27
Spares	4	None
Total Accommodations	45	52

Development Of Necessary Design Tools

The second high level problem was the availability of necessary **design tools**. Design tools are the key to top quality products. In these times of faster acquisitions and reduced ship design money, the design team gets orders to perform its tasks faster, better, and cheaper. However, the normal ship design tools and procedures were used. The typical ship design team has no tools to quickly evaluate the sensitivity of producibility changes, stability criteria, commercial vs military practices, risk assessment, or overall mission performance to name a few. Inadequate tools are the principle reason why decisions are not timely, designs have difficulty converging, and overall product quality is limited. This SWATH design was hampered by inadequate tools.

Availability Of The Design Team

The composition of the design team is critical to the success of any project. The selection of all design personnel (including design management) must be made with some deliberation by the engineering organization. There are several items worth mentioning. The ship design manager (SDM) must possess the leadership skills to hold the team together thru the rough times. As the team members are assigned, it is important that members assigned are compatible with one another.

As a design team is assembled, it is important to consider the experience mix of the assigned personnel. The team should include a proportionate numbers of junior engineers (3 years or less), working level engineers (5 to 10 years), and senior engineers (15 years and above). The experience mix will offer the design team complimentary views of new ideas and ideas which have worked in the past.

Another factor which effects the composition of the team is the NAVSEA organization structure. There are many technical codes, contractors, and laboratories that support them. They each have an area of speciality. However, more people leads to more interfaces and more difficult systems

TABLE 2
AREAS OF DIFFICULTY
PERFORMANCE MEASUREMENT

Area of Difficulty	+	o	-
Development of OR	X		
Development of TLR		X	
Development of Design Reqts from TLR		X	
Integration of ABS rules and CFR		X	
Design to Budgets (HVAC, Weight, Power, schedule, volume, cost)		X	
Effectiveness of the Design		X	
Convergence of the Design		X	
Decision Making			X
Synergism of the Design		X	

integration. This complex NAVSEA organizational structure has made systems integration more difficult.

Reasonableness Of The Design Schedule And Resources

The amount of **time and funding** provided to the design team has a impact on the final product. A review of history shows an amazing variance of costs and time budgets on various "in-house" ship designs. Typically, the design team is forced to meet the constraints imposed by the acquisition program strategy. However, it is the responsibility to the system engineering managers to evaluate the risk of design schedules and budgets with the proposed acquisition strategy. The SDM should factor in contingencies (i.e., $ and time) to the master schedule after performing a risk assessment.

The Common Hull SWATH program was scheduled in the wake of the performance displayed on the T-AGOS 19. The design cost and schedule was not as constrained (as the T-AGOS 19) but was optimistic considering the requirements of both designs. The decision was made that both programs share the Research and Development (R&D) costs to develop the respective designs. A program decision was made at the end of T-AGS (OCEAN) preliminary design to start the T-AGOS 23 preliminary design. This decision was made based on technical, programmatic, and operational considerations.

The completion of the T-AGOS 23 contract design cost $5.5M from the initiation of the T-AGS (OCEAN) preliminary design. Several months after the T-AGS (OCEAN) preliminary started, the decision was made to perform foreign SWATH testing. The foreign SWATH tests were performed in an attempt to manage the technical risk. An additional $5M was reprogrammed to perform these tests. However, the tests were successful programmatically but the results of the tests had little impact on the output of the NAVSEA design since the results were available near the end of contract design.

Design Team Decision Making

Design teams typically do not have broad decision making authority. The decision making power of the SDM, PNA/DIM, and TGMs is limited to the what the NAVSEA matrix management structure will allow. This varies from project to project and is very dependent on the SDM. Experience has shown that collocated design teams have a stronger project cohesiveness.

Many designs have a problem where decisions are delayed on critical issues. Specifically, a conflict between the project management staff and line management occurs. This situation can reach the top levels of NAVSEA 05 directorate. The time to reach a final decision or conclusion on a specific design issue can take weeks. This is inefficient, disruptive, and expensive. It hurts the overall ship design quality and process, and has dramatic schedule implications.

RECOMMENDATIONS TO IMPROVE SYSTEMS ENGINEERING

Each of the five high level problems can be ameliorated. Some key changes are required for each issue.

Requirements Definition

This is most important. The design starts from here. It is suggested that more vigorous and serious attention be paid to requirements definition. The SDM staff, PMS, OPNAV sponsor, and SCIB staff representatives must develop specific design requirements that are not vague or ambiguous. It is important to have requirements that meet the acquisition constraints. The requirements must be developed early, accurate, fixed, and "real". The comprehensive design solution will be hampered unless these requirements are clearly defined. The participants must make sure the requirements can be adequately engineered in the cost and time available and at an acceptable risk.

System Engineering Tools

The tools required here are both specific technical tools for the functional organization and total ship tools which can be used by the ship system managers for decision making. It is essential that **Measures of Effectiveness Tools (MOEs)** be developed for ship design. These tools exist in the combat system arena and are used in war game simulations. In the HM&E area, tools to evaluate the sensitivity of commerciality, risk analysis, performance, cost analysis, producibility, etc. are so important to evaluate total ship implications. However, these tools don't exist or they are in

their infancy. These tools are essential for the Systems Engineer. Without them the ship design process will remain stagnant.

Design Team Organization

To improve overall design team effectiveness, it is recommended that **instead of many speciality engineers working 25% of their time. System Engineers (generalists) should be developed where they can cover more than one engineering discipline and assigned to programs 100% of the time.**

Some suggested organizational changes to support future design teams include:

1- Propulsor Design.
2- Total ship Configuration Arrangements (Ship Arrangements, Machinery Arrangements, Topside Arrangements)
3- Weight and MEL
4- Manned Systems Engineering, Systems Safety, and RMA.
5- Stability, Hydrostatics and Hydrodynamic performance
6- Static and Dynamic Structure Analysis.
7- Consolidation of Fluid Systems

Adequate Design Resources

When the ship design staff commits to the project, costs, schedules and risks are all attributes that must be traded off in development of realistic and achievable programs. The ship design management staff should also have algorithms of standard costs and times of classical ship design functions. The development of important project management tools should be aggressively pursued to assist the system engineers in this important early stage activity.

Design Team Decision Authority

The ship design management staff should have more control of technical decisions. The SDM and TGMs have the total ship viewpoint to make the "good enough", or Level I, decisions required of the ship design. They are required to view the system from the outside. Without the authority to make the daily system engineering decisions the ship design will not be balanced and reflect the best product from a systems engineering perspective.

Transition To Production Recommendation

A pure systems engineering approach to ship design would require considerable reorganization within NAVSEA 05. Some change is required. The recommendations suggested should be considered not just for early stage design. This paper has not addressed the transition to the construction phase. However, the current NAVSEA organization puts a large responsibility on the SUPSHIP offices to perform this systems engineering function. NAVSEA should review the current detail design and construction process from the systems engineering perspective.

SUMMARY

Systems Engineering has an important role in the future naval ship design process. It is evident from the Common Hull SWATH case study that change is required. Even though, the T-AGOS 23 design was completed very successfully, the process could have been significantly improved. The changes required for improved ship designs include nailing down the ship requirements definition process, providing the ship design team adequate design and decision tools, improved organizational structure to streamline interface management, providing adequate time and financial resources to the design team, and providing the design team management more decision authority.

Improvement in the Systems Engineering process is necessary to reduce future costs and problems. The responsibility to reach this objective is in the hands of todays' NAVSEA engineers and managers.

References

[1] System Engineering Semester Notes, Spring 1990, Johns Hopkins University Applied Physics Laboratory.

[2] NAVSEA 05 Design Team, T-AGOS 23 Preliminary Design Report, September 1988.

[3] NAVSEA 05 Design Team, T-AGOS 23 Contract Design Report, December 1989.

[4] NAVSEA 05 Design Team, T-AGS (OCEAN) Preliminary Design Report, April 1988.

[5] Management of Ship Design at the Naval Ship Engineering Center, ASE, 12th Annual Technical Symposium, Spaulding and Johnson.

[6] NAVSEA Ship Design Group, Ship Design Histories Volume I & II.

COMBAT SYSTEM ENGINEERING PROCESS

Mr. William D. Tootle
Director of Combat System
Architecture and Engineering
Combat Systems
Research & Technology Group
(SEA 06R1)

Mr. Robert H. Compton
Senior Combat Systems Engineer
Combat Systems Research & Technology
(SEA 06R1)
Naval Sea Systems Command

April, 1991

Approved for Public Release
Distribution Unlimited

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ABSTRACT

This paper will describe the Combat System Engineering Process and the various tasks that must be performed in order to develop the combat system alternatives required to be presented to the SCIB at Milestone 1. We will show that the alternatives must not only address the expected warfighting capabilities, but must also include ship impact, cost and schedule risks, and must identify any performance shortfalls that may exist. We will start with the issuance of the TOR and continue through the development of the Development Options Paper. The process starts with an analysis of the threat and includes an examination of the concepts of operation, scenarios and battle overviews; determination of the required warfighting capabilities and performance characteristics; assessment of available hardware/equipment; generation of alternative combat system configurations and an assessment of each alternatives expected performance. The process will conclude with inputs to the DOP and a recommended combat system configuration. Constraints such as funding, OPNAV requirements, organizational structures, and acquisition approach will have an impact on the implementation of the CSEP. However, it must be kept in mind that the more steps omitted from the process and the fewer products developed, the higher the risk of a sucessful system development being completed on time, within budget, and meeting the system requirements. On the other hand, if the front end of the process is followed correctly, it may avert schedule slips and cost overruns. Tailoring is best accomplished by not deleting steps and products, but reducing or refining the scope of each in order to accommodate the limits caused by constraints.

LIST OF FIGURES

ABBREVIATIONS

COO	Concept of Operations
CSEP	Combat System Engineering Process
DOP	Development Options Paper
NTIC	Naval Technical Intelligence Center
OR	Operational Requirements
SCIB	Ship Characteristics Improvement Board
TOR	Tentative Operational Requirements

Introduction

The Combat System Engineering Process (CSEP) is an overall process for ensuring that engineered and tested ships delivered to the fleet have fully interoperable combat systems which can operate as an integrated and synergistic force in support of Battle Force Warfare tasks. In addition, it is also used to engineer, test and integrate advanced combat systems and warfighting capabilities into existing ship classes. The implementation of the process must be tailored to the specific application. Constraints such as type of ship, funding, scheduling, OPNAV requirements, organizational structures and acquisition approach can have an impact on the CSEP. However, it must be kept in mind that the more steps omitted from the process and the fewer products developed, the higher the risk of a successful combat system development being

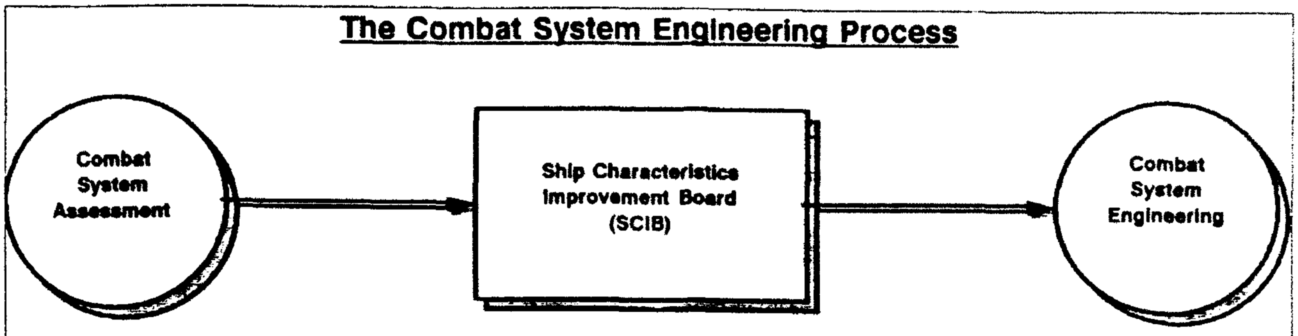

Figure 1

completed on time, within budget, and meeting the system requirements. On the other hand, if the process is followed correctly, the expected warfighting capabilities can be predicted and research and development efforts can be focused to meet the required capability thus reducing the possibility of schedule and cost overruns.

The Combat System Engineering Process supports both new ship design as well as planned improvements to existing ship classes. It consists of two distinct phases, Assessment and Engineering, separated by presentations to the Ship Characteristics Improvement Board (SCIB). A top-level view of the process is shown in Figure 1. The Assessment Phase begins at Milestone 0 with the issuance of the Tentative Operational Requirements (TOR) document or a Ship Class Warfighting Shortcoming Letter and culminates with the presentation of several combat system options to the SCIB.

The Engineering Phase begins after a SCIB decision and the issuance of an Operational Requirements (OR) document and culminates with the development of a contract design package. This paper will deal primarily with the Assessment Phase.

Concepts of Operation, Scenarios and Battle Overviews

As shown in Figure 2, there are several steps that must be performed in order to adequately respond to the TOR and provide combat system options to the SCIB.

To start the process, it is necessary for the Chief of Naval Operations to officially issue a TOR document for the Project. In addition, several additional inputs are required, including a threat assessment.

The threat assessment defines the present and future threats in terms of characteristics and capabilities that the ship is expected to encounter while performing it's mission. The threat assessment is developed by the Naval Technical Intelligence Center (NTIC) and normally requires six to nine months to produce. Frequently, this schedule does not support the project schedule and the engineer performing the combat system assessment must develop an "interim" threat assessment based on existing NTIC documents to support the early phase of the assessment. A good threat assessment will not only address the near term or known threats, but it will also address projected and technologically feasible threats in the timeframe of concern.

In order to determine and develop the warfighting capabilities required to meet and defeat the projected threats, an environment in which the ship might find itself must be developed. This includes the development of a Concept of Operations (COO), Scenarios and Battle Overviews.

The COO is a projection of how the Navy intends to operationally employ the ship by describing the role of the ship in the Navy's overall mission. It defines the required warfare areas such as AAW, ASW, ASUW, STW, AMW, MIW, C3, etc. The operational environment in which the ship must perform is stated and includes the sea state, weather and geophysical waters. In addition, it provides a brief overview of the threat the ship is expected to encounter while performing its mission and defines the ship performance requirements directly related to the mission such as speed, endurance and range. The primary, secondary and contingent operational roles along with the applicable readiness conditions are also stated.

A projected scenario is developed which provides a description of the overall strategic situation in the area of operations and provides descriptions of operational situations that the combat system engineer can use to evaluate the adequacy of the proposed warfighting capabilities and later elements of the combat system. The strategic situations can be based on historical data or the expected future political climate. A Battle Overview is developed to describe an isolated local tactical conflict within the

The Combat System Engineering Process
Concept Exploration / Definition Phase
(Feasibility Study)

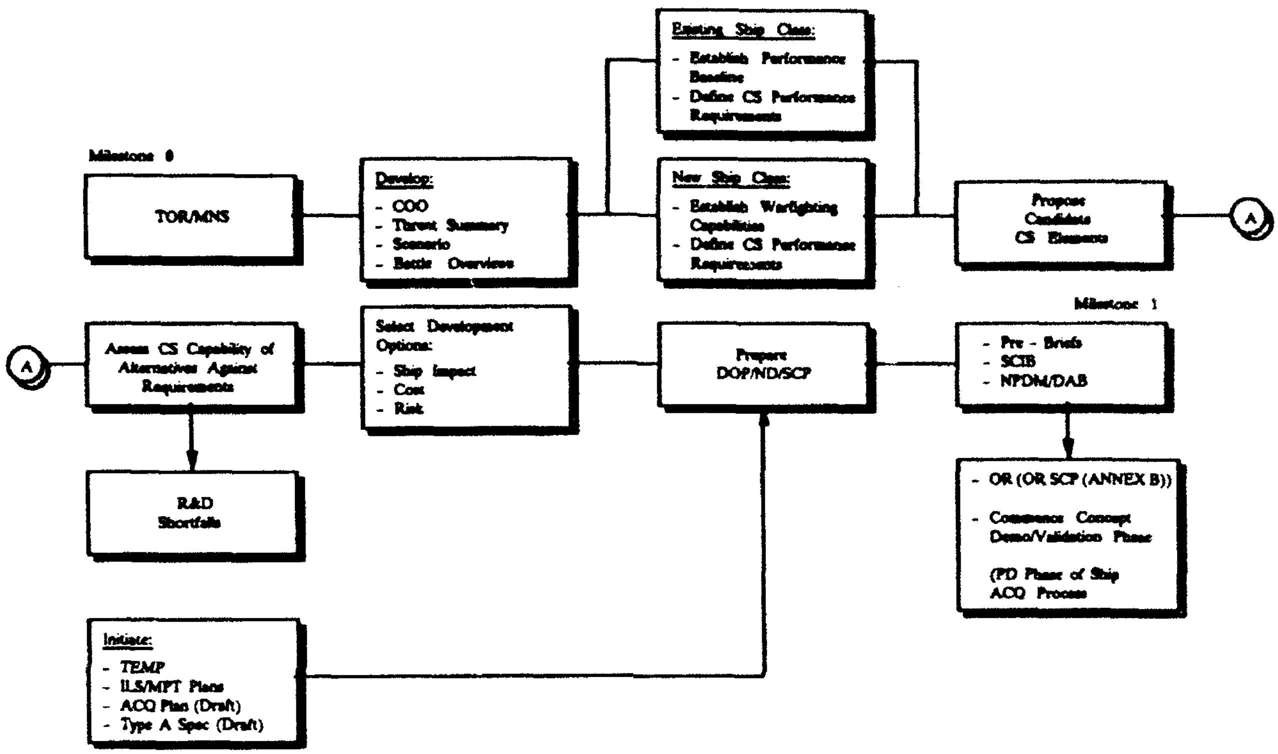

Figure2

scenario. The Battle Overview examines the various operational tasks, geographical locations, weather conditions and multiple threats in all the applicable warfare areas in which the ship will be operating. It is customary to develop two or more scenarios with several Battle Overviews for each scenario in order to fully exercise the projected warfighting capabilities required. Normally the Concepts of Operations, Scenarios and Battle Overviews are reviewed by regular Navy personnel to ensure that they are reasonable and realistic.

Establishing Warfighting Capabilities Required

Using the Tentative Operational Requirements, Concepts of Operations, Threat Summaries, Scenarios and Battle Overviews, (see Figure 3), the required warfighting capabilities are identified. Each warfare area is examined in the context of the operational situations described in the above documents. Considering the various parameters of the threat, geographical location and the required missions and tasks, the top-level warfighting capabilities are determined. The capabilities identified describe the operational capabilities required of each warfare area in support of the overall combat system. A typical example for ASW is to "passively detect enemy submarines at a range that will minimize their ASM effectiveness". In addition, each warfighting capability requirement must be examined to determine to what extent it must support the top-level functions of detect, control and engage of the combat system. Figure 4 is an example of how each requirement is documented. Once all the warfare area requirements, including command and control, have been identified, they must be integrated into an overall set of capabilities required for the combat system.

After the required warfighting capabilities have been identified, the required performance level for each requirement must be established. Typically, a specific battle overview with its associated threat(s), weather conditions and Geographical location is selected to determine the specific performance parameters for each of the top-level combat system functions. This process results in determining the detection range, based on threat characteristics, at which a particular threat must be detected in order to successfully engage, the time required to establish a firm track and identification and to determine the method of

Combat System Capability Development

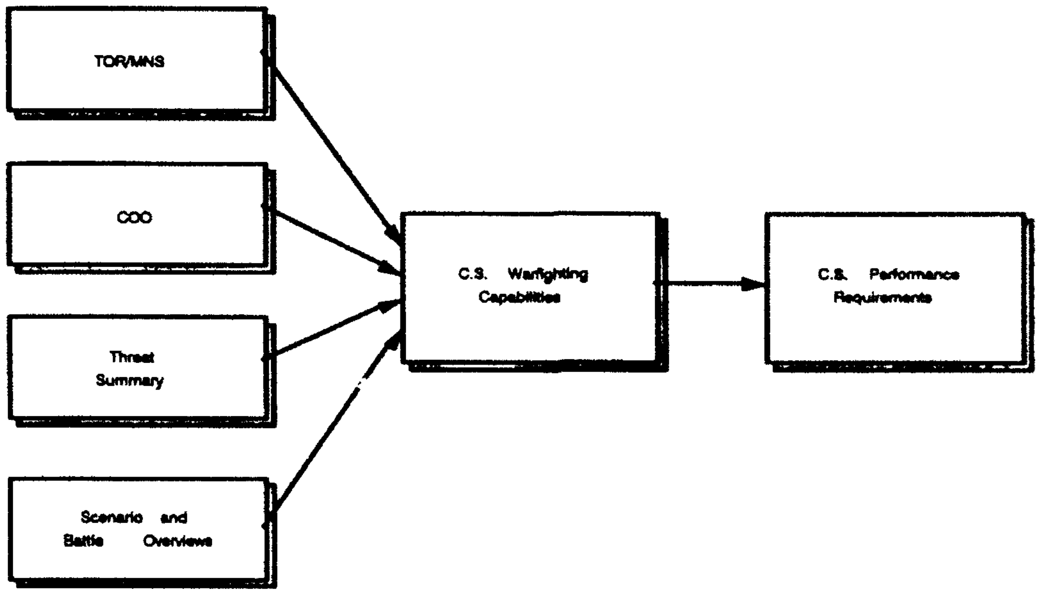

Figure 3

Combat System Warfighting Capabilities (Examples)

Warfare Areas / Function	ASW	AAW	ASU	Other Warfare Areas
Detect	Detect Subsurface Targets	Detect Air Targets	Detect Surface Targets	
Control	Track Subserface Targets	Track Air Targets	Track Surface Targets	
Engage	Engage Subsurface Threats Using Hard Kill or Soft Kill Effectors	Engage Air Threats with Hard Kill or Soft Kill Effectors	Engage Surface Threats	

Figure 4

Combat System Performance Requirements (Examples)

Function \ Warfare Areas	ASW	AAW	ASU	Other Warfare Areas
Detect	• Detect subsurface targets out to the third convergence zone. • Actively search within a 270° azimuthal sector. • Provide 360° of passive azimuthal coverage.	• Detect & tract 256 air targets. • Detect air targets at altitudes of 100 feet to 50,000 feet. • Provide hemispherical detection of air targets.	• Detect surface target at over-the-horizon ranges and 360° azimuth. • Detect & track 128 surface targets.	
Control	• Simultaneous control of 2 ASW aircraft. • Control ASW aircraft in vectored attacks on submarines. • Correctly classify 85% of active contacts and 75% of passive contacts.	• Control four (4) combat air petrol (CAP) aircraft at same time. • Perform auto correlation of air contacts from all sources. • Correctly identify air contacts with 95% accuracy.	• Control of Surface surveillance aircraft. • Correlate surface contacts from all sources. • Perform OTH targeting and navigation data calculations automatically.	
Engage	• Engage submarines with over-the-side torpedo within 0 to 40 kyds. • Conduct simultaneous engagement of 2 threat submarines with ownship weapons.	• Conduct 4 air intercepts simultaneously with ownship weapons. • Engage 7 simultaneous air threats. • *Defeat air threat with soft-kill* weapons within 1 kyd to 25 nm.	• Engage surface targets with surface-to-surface missiles within 10 nm to 1000nm (OTH). • Engage surface targets with ASMs aboard organic and *non-organic* aircraft.	

Figure 5

engagement. This process must be repeated several times for the different Scenarios and Battle Overviews in order to determine the stressing detect, control and engage performance requirements. The various performance parameters must be consolidated to develop an integrated set for performance parameters for each warfare area and the overall combat system. A typical description of performance requirements are listed in Figure 5.

The process described above is normally performed in response to a TOR. However, the same process can be used to propose upgrades to existing ships combat systems. For an existing ship, the Chief of Naval Operations normally will issue a ship warfighting capabilities "shortfall" letter in lieu of a TOR. The "shortfall" letter documents the desired warfighting capabilities that the current combat system does not have. The combat system designer uses the process described above to determine the overall combat system performance level required. However, in this instance, he has to determine the current performance capability of the existing combat system in order to determine what is required to bring the overall combat system to its required full performance level. In this instance, the difference between the capability that is required and the capability that exists is the primary concern of the combat system designer. His or her primary efforts will be to build on and make maximum use of the existing capabilities in order to reduce ship impact and cost. The results of this analysis will provide the basis for inputs to the Warfighting Improvement Plan. The desire to replace an existing capability that meets the performance requirements because of the availability of a more capable system must be avoided.

Alternative Combat System Configurations

Once the missions and tasks have been examined and the warfare areas have been analyzed to determine the warfighting capabilities required to engage and defeat the expected threats, the combat system designer must look for

Combat System Element Alternatives

Function / Warfare Areas	ASW Requirements	Alternative 1	Alternative 2	Alternative 3
Detect	• Detect subsurface targets out to the third convergence zone. • Actively search within a 270° azimuthal sector. • Provide 360° of passive azimuthal coverage.	• Hull Mounted Sonar AN/SQS-53B • Towed Array AN/SQR-19(V) • Ownship Sonobouys • Sonobouy Processor AN/SQR-17 (Ownship Only)	• Hull Mounted Sonar AN/SQS-53C • Towed Array AN/SQR-19(V) • LAMPS MK III (Sonobouys) • Ownship Sonobouys • Sonobouy Processor AN/SQR-17 (Ownship & LAMPS MK III)	• Hull Mounted Sonar AN/SQS-53B • Towed Array AN/SQR-19(V)
Control	• Simultaneous control of 2 ASW aircraft. Control ASW aircraft in • vectored attacks on submarines. • Correctly classify 85% of active contacts and 75% of passive contacts.	• Antisubmarine Warfare Control System (ASWCS) MK116 MOD 8 • ASW Aircraft Link/Comms	• ASWCS MK 116 MOD" • LAMPS MK III (Data Link)	• Control Panel MK 309 • ASW Aircraft Link/Comms
Engage	• Engage submarines with over-the-side torpedo within 0 to 40 kyds. • Conduct simultaneous engagement of 2 threat submarines with ownship weapons.	• Surface Vessel Torpedo Tubes (SVTT) Mk 32 MOD 14 (3 tubes/mount) • Torpedo MK50 • SEA LANCE [Vertically launched ASW stand-off weapon (SOW)]	• SVTT MK32 MOD14 (3 tubes/mount) • Torpedo MK50 • LAMPS MK III (Torpedo MK 50) • Sea Lance (ASWSOW)	• SVTT MK32 MOD14 (2 tubes/mount) • Torpedo MK50

Figure 6

ways to satisfy the combat system requirements. To meet these requirements, he must propose candidate combat system equipments that meet or exceed the combat system warfighting requirements. Normally he should first consider the warfare area requirements and proceed to group the selected combat system elements into alternative combat system configurations. In selecting the various combat system elements, the combat system designer must keep in mind the Concept of Operations, Threats, Scenarios, Battle Overviews, and most of all the Warfighting Capabilities and Performance Requirements. Figure 6 is an example of candidate elements to meet an ASW requirement. In developing alternative combat system configurations, some combat elements may appear in each configuration. The alternatives recommended are not intended to provide a "shopping list" from which the decision makers will choose individual combat system elements. Rather, they are intended to provide integrated combat system configurations that will meet the total combat system requirements.

Figure 7 is an example of typical candidate combat system alternatives. In addition, they are intended to provide the decision makers with sufficient information in order to make "informed" decisions with respect to the expected performance. In selecting combat system elements, the combat system designer has several sources from which to choose. They include existing off-the-shelf equipments, equipments that are undergoing test and evaluation, ongoing research and development programs and foreign military equipments and systems. In selecting candidate combat system elements, the designer must keep in mind the development status of each element and ensure that it can support the ship design and construction schedule. Other factors impacting the selection of the combat system elements and alternatives configurations are hull design impacts, allocated space, weight and volume, compatibility of components and signatures.

Warfighting Capability Assessment

In order to determine the alternative combat system configurations that will be recommended, an assessment of each configuration must be performed. First and foremost must be an assessment of the expected overall combat system performance. It is important that the as-

Combat System Alternatives (Examples)

ALT's	ASW	ASU	AAW	COMM	C^2	EW	NAV
ALT 1	Hull Sonar SQS-53B TASOR-19 Sonobouys SQR-17 ASWCS MK 116-8 ASWA/CCOMMS SVTT Mk 32-14 Torpedo Mk 50 SEALANCE	SPS-64 Radar MK 92 FCS Harpoon 76mm Gun MK24 TDT KAS-1E/O	MK 92 FCS MK 15 CIWS	HFXMTRS(3) HFRCVRS(5) UHFXCVRS(5) VHFXCVRS(1) SATCOMM	CDS LINK II HYCATS MK 12 IFF	ALR-66 ESM MK36 DECOY LCHR SRBOC DECOY IR DECOY	TACAN WSN-5 OMEGA GPS INTPS NAV Radar
ALT 2	Hull Sonar SQS-53C TASOR-19 Sonobouys SQQ-28 ASWCS MK 116-7 LAMPS MK3 LINK SVTT MK 32-14 Torpedo MK 50 SEALANCE	W-160 Radar Harpoon OTO 76mm Gun FLIR E/O	SEA VULCAN 25mm Gun w/STINGER Turret MK 28 25mm Guns (2ea)	HFXMTRS(2) HFRCVRS(4) UHFXCVRS(3) VHFXCVRS(1) SATCOMM	CCS C&C (w/data bus) HYCATS MK 12 IFF	SLQ 32(V)2 LADS Chaff System	WSN-2 MX 1157 SAT/OMEGA INTPS SPS-67 NAV RADAR UQN-4 Depthsounder UL-100-4 EM Speed Log
ALT 3	Hull Sonar SQS-53B TASQR-19 CP MK 309 ASWA/CCOMMS SVTT MK 32-7 Torpedo MK 50	SPS-64 Radars Harpoon & OTOMAT OTO 76mm Gun SAR-8 EO/IR	30mm (BMARC) Gun 20mm (BMARC) Gun	HFXMTRS(3) HFRCVRS(5) UHFXCVRS(4) VHFXCVRS(1) SATCOMM	WSA 423 C&C LINK 11 MK 12 IFF	UAA1 RACAL CUTLASS ESM CYGNUS ECM 3" Rocket Decoys MK 34 RBOC Decoys	TACAN WSN-2 SPN-25 SATNAV

Figure 7

sessment be performed at the system level to determine overall capability and not just the expected equipment performance. The expected performance for each alternative must be compared to the combat system performance required. Figure 8 is a typical example of the combat system assessment summary required. Any performance deficiency should be noted and an attempt should be made to find a solution. Some of the other factors that impact the capability assessment include the complexity of the combat system architecture and the required manning, the electromagnetic compatibility of the various components and the availability and location of space on the hull to accommodate the various sensors that are required. Sensor locations can have a significant impact on the overall combat system performance.

Research and Development Shortfalls

When a performance deficiency has been identified, it must be determined if the capability exists in our current inventory. If it does exist, the new combat system element can be included in the appropriate configurations to eliminate the performance shortfall. However, if the capability does not exist, it is identified as a research and development (R&D) shortfall. R&D shortfalls are classified as (a) the need for improved capability of an existing system or (b) the need for a new capability. The emerging technologies that might support the development of the required capability must be identified and the time frame when needed must be stated. The combat system performance assessment and identification of R&D shortfalls present the decision makers with several options including the following: reduce the performance requirements to the capabilities of available and existing systems; proceed with the acquisition and backfit capability when available while initiating budgetary action for the needed improved warfighting capability; initiating exploratory research and development efforts to obtain the capability; or cancel the TOR. Whatever the decision may be, it will be an informed one.

In responding to the combat system performance requirements and developing alternative configurations to meet those requirements, the combat system designer will subject all of them to the performance assessment process in order to eliminate those that do not meet the requirements.

Combat System Performance Assessment Summary

ALT's	ASW	ASU	AAW	COMM	C^2	EW	NAV
ALT 1	G	G	G	G	G	G	G
ALT 2	Y	G	Y	G	Y	Y	G
ALT 3	Y	Y	R	G	Y	Y	G

Green (G) - Meets or exceeds requirements.

Yellow (Y) - Meets requirements marginally.

Red (R) - Fails to meet requirements.

Figure 8

Ship Impact, Cost and Risk Analysis

Once the alternative configurations have been reduced to those that meet the requirements or that might be acceptable, they must be subjected to a more detail ship impact, cost and risk analysis. Items that must be considered and evaluated in terms of ship impact include the following: weight is probably the most important concern from a naval architects view. Not only is the total weight of concern, but also the location and distribution of this weight. Pressure will be exerted upon the combat system designer to keep the maximum amount of weight at the main deck or below. Even more pressure will be applied to reduce the weight of topside sensors. This pressure is sometimes applied without regard to the combat system performance required; space, topside and below deck, is also critical to the combat system designer. The requirement to co-locate certain equipments and to keep those equipments within the maximum allowable separation from associated sensors reduces the options on available combat system spaces; other items that must be considered are power requirements; heating, ventilation and air conditioning; manning; and special services such as dry air and chilled water. Even though the identification and quantification of the ship impact for each of the selected alternatives are important in ship sizing, it is not always possible to identify with certainty due to the sometime concurrent development of combat system elements and the ship design. In those cases we make use of the "design budget" concept. The agreed design budget is a "contract" with the ship designer containing the maximum estimated combat system space and HM&E requirements that will be needed. This concept allows the ship design to proceed while the details of the combat system are still being defined. Each selected combat system alternative is also subjected to a cost assessment. When the alternatives consist of existing equipments, this is a fairly straight forward task. However, when elements that are under development are included, this task is most difficult. Most ship design cost estimates are based on historical data with adjustments for inflation and other factors and are weight related. With advances in electronics, combat systems are becoming smaller, lighter in weight and more costly. Because of these factors, we need to modify and improve our cost estimating process for combat system equipment. Finally, there are inherent risks throughout the combat system development process. Some of the factors include R&D efforts, cost, schedule production and political. Early identification of the risks and their impact is important in developing a risk management strategy.

Development Options Paper

The results of the combat system engineering process in response to the TOR is documented in a Development Options Paper (DOP). The purpose of the DOP is to present the decision makers with a summary of total ship alternatives, description of each alternative, advantages/disadvantages of each alternative and cost-vs-capability curves. The combat system inputs to the DOP included the following details:

- Performance level or capability
- Schedule (estimates milestones including IOC)
- Estimated R&D, Unit production and life cycle cost
- Critical technologies involved
- Risk estimation and recommended actions to reduce
- EMC and frequency spectrum assignment considerations
- Test and Evaluation issues
- Summary of potential acquisition strategies

The results of the study are presented to the Chief of Naval Operations Ship Characteristics Improvement Board. If the presentation is successful, the Board will select an option, with modification if desired, and authorize the development of an Operational Requirements (OR) document. When the OR has been signed and promulgated, the ship project is ready to begin Preliminary Design.

The Challenge

Develop the tools that will allow a timely and cost effective evaluation of various combat system alternatives. In the future, both time and dollars will be in short supply. The tools must allow sufficient information to be developed in order for decision makers to make informed decisions. However, the process must be affordable in both time and dollars. In addition, there is a need to increase our design and analysis efforts and support them with continuous funding. These efforts should include an examination of new and projected threats, future warfighting capability requirements, new ship designs and emerging technologies. It would be most beneficial if these tasks were the result of an integrated team of ship and combat system designers. This team could establish and maintain continuing baselines for the types of ships expected to be required in the future. It would be most helpful if these baselines reflected planning prior to Milestone 0. With early identification of future warfighting capability requirements and focusing of our R&D efforts to meet those requirements, the ship and combat system designer could respond to a specific ship TOR with a design that would fully provide the capabilities required in a timely manner.

The Effects of Confined Water Operations on Ship Performance: A Guide for the Perplexed

Larrie D. Ferreiro, PE
Naval Architect
Preliminary Design Division
NAVSEA 50112
Naval Sea System Command

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ABSTRACT

Operations in confined waters (both shallow and width-restricted) are quite different from those in the open ocean, and in some ways are more dangerous. This paper acts as a guide to some of these differences, pointing out where the dangers lie, and providing some guidelines for designers and operators to consider. The paper covers the following topics: definition of confined waters; effect on resistance and powering; considerations for ship maneuvering; sinkage and trim effects; ship motions; and other effects. Most of the topics are dealt with in a qualitative manner, but some methods of predicting confined water resistance are presented.

INTRODUCTION AND EXECUTIVE SUMMARY

Introduction

The primary reason for my examining the confined-water performance of ships is the recent US Navy experience in Persian Gulf operations, and the greater likelihood of future Navy operations in coastal and confined waters, especially in low-intensity conflicts. Operations in such waters are quite different from those in the open ocean, and in some ways are more dangerous. This paper will hopefully act as a guide to some of these differences, point out where the danger lies, and outline some methods for predicting ship behavior in confined waters.

This paper is a compilation of an extensive literature search on confined waters operations, which I did during my Navy long-term training program at the University College London. It presents a broad overview of this topic, and is not intended as a rigorous examination of all factors of performance. It is not intended for predicting the specific performance for a particular ship, but rather describes performance in a general sense for a broad range of ship types. The exceptions to this are the methods for predicting shallow water resistance, described in Annexes A & B.

Executive Summary

What are confined waters?

Confined waters can be divided into two types, shallow and width-restricted water. 'Shallow' generally means less than twice the draft, although it can be speed dependant. "Restricted" means less than 10 ship widths across. The bottom and side topographies can vary greatly, and there may be fresh water influx.

Resistance and powering

The principal parameter in defining shallow-water resistance is "critical speed", or $V/\sqrt{gh} = 1$. This gives the speed of a wave in shallow water of depth h. When a ship is at a subcritical speed in shallow water, its resistance increases over that in deep water, primarily due to increased wavemaking resistance. As the ship approaches critical speed, the resistance increases even further over that in deep water. It reaches a maximum somewhat below critical speed, however, because the maximum squat occurs below critical speed. At critical and supercritical speeds, this resistance augmentation decreases, eventually to below that for deep water. Restricted waters amplify these effects.

The effect on powering is hard to define, since the effects on hull efficiency elements are not well known. However, it appears that one should use the values for the equivalent deep-water speed. Fresh water effects may be neglected.

Two methods of predicting resistance are given, Schlichting's and Millward's. The first is relatively easy to use, though is only good for subcritical conditions. The second is highly theoretical and usable only by computer. Both predict only wavemaking resistance. Since the im-

portant speed regime is subcritical (supercritical resistance approaches that for deep water), I recommend using Schlichting's method for resistance, and the ship's deep-water hull efficiency elements for the powering calculations.

Maneuvering

The basic rule is, "things get worse". The restricted flow causes sideways motion to be sluggish, and this is not helped by thrusters. A ship maneuvering near a bank will be bodily drawn to it, while the head is pushed out. In the middle of a channel, it will be directionally unstable, so will tend to veer from bank to bank. Normal ship-ship interactions are worsened, as the ship's pressure field extends further in shallow water. Ships will stop quicker but a single screw ship will not wear off to one side as readily, and may expose the broadside to a collision.

Sinkage and trim

A ship will squat more by the stern in shallow water. Consequently, initial trim by stern should be avoided. While operating over shoals, the bow will be first sucked in, then violently repelled, causing both bow and stern to overshoot the normal sinkage limits. Fresh water will increase the draft somewhat.

Ship motions

The reduced depth provides a cushioning effect, decreasing both heave and pitch amplitudes, and reducing roll period. Minimum operating depths should be based on ship motions and sinkage effects.

Other effects

Ship vibrations are magnified; underwater acoustics are affected; underwater shock effects are increased; the hull and inlets may foul more.

WHAT ARE CONFINED WATERS?

Definition

Confined waters can be divided into two types, shallow waters and width-restricted waters (e.g., channels). Generally, the second type (which are called simply "restricted") involve the first type. The hydrodynamacist will define "confined waters" as that which will cause at least a 1% increase in resistance (ref. 3). This is not a good definition for the ship-driver, however, so more amenable definitions are:

Shallow	$\leq$ 2 x draft for slow speed (ref. 2)
	$\leq$ 1/2 length for high speed
	or $V/\sqrt{gh} \geq 0.4$ in general (ref. 1)
Restricted	$\leq$ 10 ship widths (ref. 4)

Features

The nature of confined waters can vary considerably, and this can have a substantial effect on operations. Shallow water can have quite irregular terrain; the depth transitions can be very gradual or quite abrupt. The composition of the bed appears to have little effect on propulsion or maneuvering characteristics, but of course grounding on a silty bottom is far less damaging than on a rocky one (ref. 2).

Restricted waters can encompass anything from deep fjords to shallow channels. The banks can be slab-sided or sloping, and the width may be constantly changing. Both restricted and shallow waters may have lots of plant life, which may increase fouling, clogging of inlets and propellers, etc. Finally, many confined waters are close to river mouths, and the fresh water influx will affect draft and resistance to some extent, as will be explained later.

OPERATIONAL CONSIDERATIONS IN CONFINED WATERS

Resistance and Powering

The effects of confined waters on resistance and propulsion have defied rigorous, comprehensive analysis for some time. This is in part because many of the interaction effects between wavemaking, viscous resistance, propeller inflow, etc. are more pronounced than in deep water, and in part because many of the simplifying boundary conditions, although useful in deep water calculations, are not applicable in shallow or restricted waters.

This section will cover (1) the effects of shallow water on resistance, (2) the effects of restricted water on resistance, (3) their effects on powering, (4) fresh water effects, and (5) methods of predicting confined water resistance.

Effects of Shallow Water on Resistance

This is the subject that has been covered in the most depth (pardon any puns) by naval architects. This subject has at its core the term "critical speed", which is the speed of a wave in a particular depth of water. It is given by the Froude depth number, $F_h = V/\sqrt{gh} = 1$, where V is the speed and h is the water depth. Therefore, $V/\sqrt{gh} < 1$ is "subcritical speed", and $V/\sqrt{gh} > 1$ is "supercritical speed". You may note there is no term for ship or wave length; in sufficiently shallow water (less than 1/2 wavelength), wave speed and therefore wave resistance is dependent only on depth.

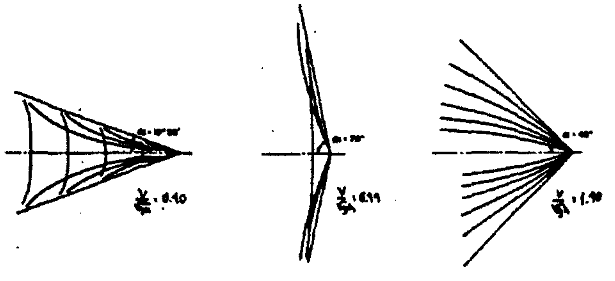


Figure 1
Effect of Shallow Water on Wave Pattern (ref. 1)

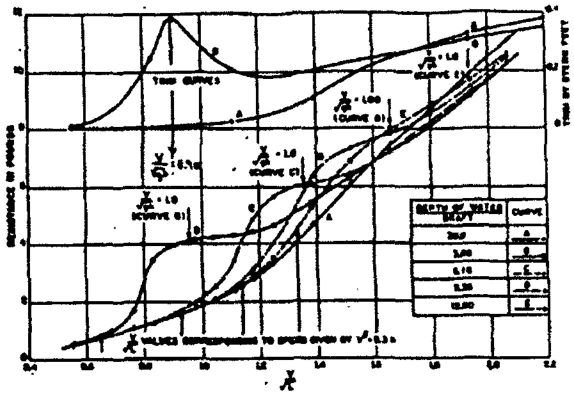


Figure 2
Resistance and Trim of a Destroyer in Shallow Water (ref. 1)

Increasing the speed in shallow water affects the ship resistance in three stages (ref. 2):

1) **Subcritical speed** ($V/\sqrt{gh} < 1$) - the resistance is greater than that for deep water, due to three effects:

(a) Increased frictional drag due to the Venturi effect between the hull and sea bed; the flow speed is increased. This also affects propeller loading (see effects on powering), but the actual increase in drag appears to be small compared with the next two effects.

(b) Increased wavemaking resistance due to changing wave pattern (Fig. 1) and the greater amplitude of the waves themselves. This increase in energy needed to make waves is by far the largest factor in the augmented resistance; indeed, the methods of prediction that will be given later only address this component of shallow-water resistance, although in fact they give results that appear to include at least some of the other effects.

(c) Increased viscous resistance due to trim and sinkage, also called "squat drag" or "slope drag". The actual nature of squat will be dealt with in a separate section, but it is important to note its effect on resistance. The most noticeable effect of this component is that the actual point of maximum drag is not at the critical speed, $V/\sqrt{gh} = 1$ (as you would expect from Fig. 1), but at some value less than 1. This is because the maximum squat occurs at a speed such that the wave length in shallow water is 1.25 times the length of the vessel (ref. 2). This is shown quite graphically in Fig. 2, which plots resistance and trim against $V/\sqrt{L}$ for a destroyer running in various depths of water. As you can see from curve B (depth/draft = 3.08), the maximum squat occurs where $V/\sqrt{gh}$ is less than 1, and actually around 0.90. Fig. 3 shows the percentage resistance increase of each of those shallow water curves over the deep water curve. For the depth/draft ratio of 3.08, the higher increase occurs at $V = \sqrt{gh} = 0.90$, which nicely coincides with the maximum squat in Fig 2. This effect is generally impossible to dissociate experimentally from the increase in wavemaking resistance; in addition, the squat causes an increase in wetted surface, increasing frictional resistance, which is not generally accounted for in theory or experiment.

2. **Critical speed** ($V/\sqrt{gh} = 1$) - resistance is generally less than at the slightly subcritical speed. The ship is "riding the crest" of the transverse wave generated, and

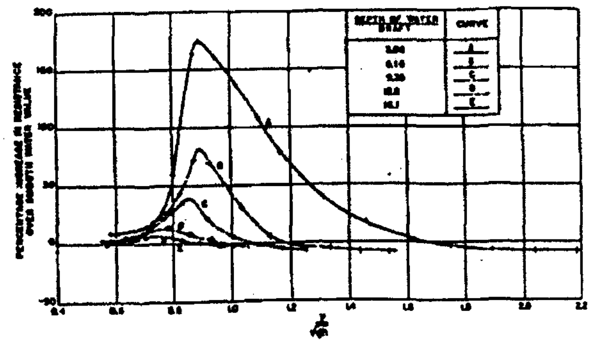


Figure 3
Percentage Increase of Resistance in Shallow Water (same ship as in Fig. 2) (ref. 4)

the squat decreases. Therefore, the slope drag is a minimum. This again is shown graphically in Fig. 3, where for curve A the percentage drag increase drops from a maximum of 170% at $V/\sqrt{gh} = 0.90$ to about 145% at critical speed.

3. **Supercritical** ($V/\sqrt{gh} > 1$) - resistance is reduced even further, eventually to below that of open water (see Fig. 3). This is caused mostly by the reduction of slope drag to a lower value than that in deep water. The ship trims to a fairly even keel.

Effects of Restricted Waters on Resistance

Since restricted waters are generally shallow, most work has centered on the combination of the two. As a rule, the restricted width serves to exaggerate the effects of shallow water, i.e., the resistance is increased even more in the subcritical region, and decreased more in the supercritical region. The first makes sense intuitively, since blockage effects are well-known; but in fact, seeming to defy common sense, a ship will have less resistance in a channel at supercritical speeds. This has been borne out in both theory and practice; an illustration of this is shown in Fig. 4, which plots the wave resistance ratio (wave/total resistance) as a function of varying channel widths. As you can see, the narrower the channel, the more exaggerated the resistance increase at subcritical speeds, and the decrease at supercritical speeds.

Effects of Confined Waters on Powering

Only 60-70% of the shaft horsepower in a ship is used to overcome resistance. The rest, of course, is taken up by propulsion inefficiencies. No satisfactory method has yet been established to determine the effects of confined waters on those propulsion factors. Actual shipboard data is rarely helpful, since operators will tend to set the

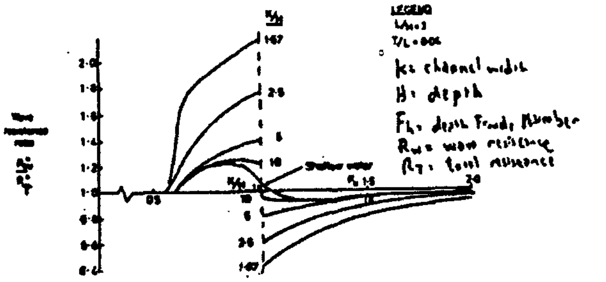


Figure 4
Effect Of Restricted Channel on Wavemaking Resistance (ref. 4)

throttle and let speed vary as it may (ref. 3). Theory is weak or non-existent; however, some experimental work has been attempted. Reference (5) describes work done on the effects of shallow water on wake fraction and thrust deduction. The author concluded that both increase as the water becomes shallower, but because of the wide scatter of data, he could not say by how much. He concluded that the method to predict resistance increase (described later) was also adequate for predicting power increase.

A sort of "handwaving argument" for this is also presented in reference (3). Basically, for a given resistance, a ship at subcritical speed in shallow water will move slower than in deep water (so the EHP will be less). However, the water close to the ship must speed up (Venturi effect), since all the water must get from front to back. This speed increase close to the ship is approximately equal to the ship speed lost due to the shallow water. Therefore, again for the same resistance, the propeller rate of rotation, wake fraction and thrust deduction at the reduced shallow water speed should remain substantially the same as for the deep water speed (and therefore, greater than the values one would get in deep water for the shallow-water speed). By the same argument, it is probably not far from the truth to assume the same is true for critical and supercritical speed.

Fresh Water Effects

As stated, confined water may be located close to fresh water sources (river mouths, estuaries, etc.) and the ship may be operating in reduced salinity water. The most obvious effect that the ship rides lower, due to the lower density, but the viscosity is also lower and this may offset resistance. In Annexe C, I have outlined a rough argument that, in fact, the total effect is probably negligible; it appears that the increased wetted surface pretty well cancels the effect of lower viscosity, giving less than a 1% reduction in resistance. This was done assuming a 50-50 mixture of fresh and salt water, though actual values range across the board. The primary fresh effect will be on sinkage and trim, as will be outlined later.

Methods of Predicting Confined Water Resistance

The two methods for predicting confined water resistance that I have found in my literature search were developed some fifty years apart, and in many ways are indicative of their times. The first was developed in 1934 in Germany by Otto Schlichting, and is based partly on theory, partly on intuition and largely on experiment. It is a graphical method, easy to use and to understand. The second method, developed in 1981 by A. Millward in Great Britain, is highly theoretical, difficult to use except by computer, and not intuitively obvious. Both produce results in fair agreement with model and ship data, within certain bounds. Schlichting's method is only good in the

subcritical region, whereas Millward's method is useful throughout the speed range (although the experimental agreement falls apart around the critical speed). Both have been extended to restricted waters cases.

Both methods assume that the increase in confined water resistance is due entirely to wavemaking. However, the effect of slope drag is taken into account somewhat by Schlichting's method, since that effect is experimentally indistinguishable from wavemaking.

Schlichting's Method – This is more accurately titled by adding "as modified by Landweber to include the effects of restricted water". It is well described in ref. (3), and presented explicitly in Annexe A. The method is fairly straightforward, and is best explained using Fig. 5. Using the ship's deep water speed/resistance curve, with the frictional line broken out, the shallow water speed/resistance curve (for a particular depth) is constructed.

The resistance is calculated in two steps. First, the "intermediate wave speed", V_I, is calculated. A ship moving at speed V_{oo} in deep water creates a wave of a certain wavelength, also with speed V_{oo}. V_I is the speed of the same wavelength in shallow water of a certain depth. Now, Schlichting assumed that the wave resistance at the speed V_I was equal to the open-water resistance. It is therefore added to the (lower) frictional resistance at the speed V_I, which gives the total resistance, Schlichting also saw that there was a further reduction in speed due to restricted flow, which he determined experimentally. That final shallow water speed, V_h, is the speed at which the total shallow water resistance is plotted.

The additional viscous drag, or slope drag, is somewhat accounted for by the fact that the total resistance at V_h is greater than the sum of the frictional drag at that speed plus the deep water wavemaking drag at speed V_{oo}.

The method has been extended to include the effects of restricted waters. Basically it is the same method, but uses the measure of "hydraulic radius", the ratio of drag to wetted surface, instead of depth. Again, it is more explicitly described in Annexe A.

This method is not useful at critical or supercritical speeds, and is not theoretically rigorous. Although some of the assumptions made may be questionable (i.e., no frictional increase), it has stood up remarkably well to experimental and shipboard observations (ref. 1, 5).

Millward's Method – This method is based on the linear wavemaking resistance theory developed in 1898 by J. Michell, and extended to both shallow water and restricted water cases. The equations and simplifying assumptions are presented in Annexe B, but it can best be used by computer, as it involves many fierce-looking integrals. It requires only the ship's principal dimensions (length, beam, draft), plus speed and water depth (and where applicable, channel width). The problem is made simpler by assuming a rectangular cross-section and parabolic waterlines.

Overall, the results show the trend of higher resistance at subcritical speeds, lower at supercritical. However, the equations seem to fall apart at the critical speed in very shallow water, where it grossly overpredicts the resistance. Fig. 6 show these results in increasingly shallow water. Note that only the wavemaking resistance is calculated; add the frictional resistance at the speed to get the total.

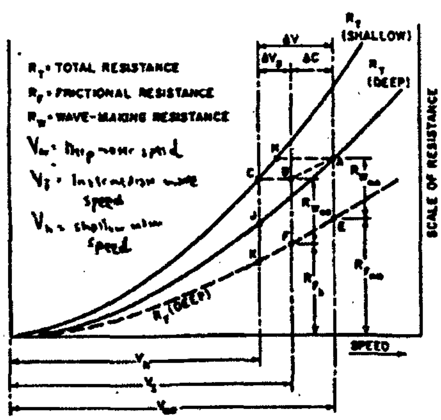


Figure 5
Schlichting's Method for Determining Shallow-Water Resistance (ref. 4)

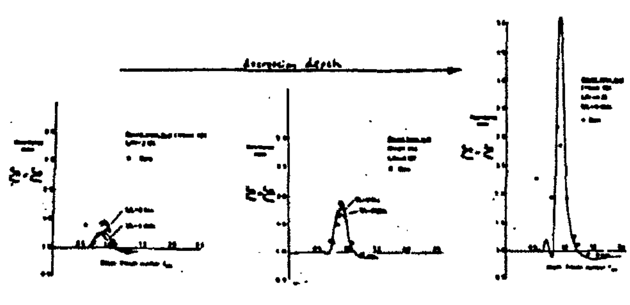


Figure 6
Experimental Agreement With Millward's Method for Decreasing Depth (ref. 4)

What to do? – Since we are interested in both combatants and merchant ships, we'll investigate what speed regimes they might operate in. A typical combatant draws about 5-8 meters, and might therefore operate in 10 meters of water. The critical speed therefore is $V = \sqrt{gh} = \sqrt{9.8} \times 10 = 10$ m/sec or 19 kts. A typical merchant ship might draw 10-12 meters, and so could operate in, say, 15 meters of water. That critical speed is $\sqrt{9.8} \times 15 = 12$ m/sec or 24 kts.

Now, merchant ships (for Navy purposes) rarely go faster than a convoy speed of 20 knots, so will always be operating in the subcritical region. The frigate, though, may often be operating in the critical or supercritical region. However – we know that in the supercritical zone, the power requirement will decrease to values less than for open water, so full-power performance and endurance will not be much affected. Because of this, we should be concerned with only the subcritical zone for both ship types. For the actual calculations, Schlichting's method is easier and (for subcritical) more accurate to use to calculate resistance. To calculate power, as explained, we would probably be fairly accurate if we use the hull efficiency elements of the equivalent deep-water speed. Any fresh water effects may be discounted.

Maneuvering

As a general rule, a ship's maneuvering characteristics are generally worse in shallow or restricted waters, and they often exhibit anomalous behavior. This is mainly due to the blockage of flow under or around the ship, and the pressure differential between the moving ship and the channel banks, or another ship. Since that is an area of great interest to both ship designers and operators, much has been written on it; I will try to highlight the important aspects, but I recommend further reading of the references cited. I will cover these areas of maneuvering: 1) slow-speed maneuvering and docking; 2) ship-bank effects; 3) ship-ship effects; 4) crash stop and tactical maneuvering; and 5) overall considerations.

Slow-Speed Maneuvering and Docking

The shallow water under the keel causes most of the flow to go around the sides of the ship. This means that less water actually flows directly into the rudder, and there is more eddymaking in the separation zone. Since the rudder lies in this zone, it requires more angle for a given steering effect. However, this situation improves with increased ship speed (ref. 1). Most maneuvering requires some sideways component of motion, which requires a considerable crossflow under the bottom. In shallow water this is blocked, so all forms of maneuvering, including docking, are much more sluggish and more difficult to perform. One operator put it well when he said that ships "sulk" under these conditions (ref. 2). Devices such as bow and stern thrusters, auxiliary propulsion units, or other steerable thrusters would help the ship's steering in shallow water, but would have little effect on any "crabbing" or sideways motion, since the required bottom crossflow will still be blocked.

Ship-Bank Interaction

The most noticeable effect of restricted water operation, to the ship driver, is the tendency for a ship sailing close to a bank to be bodily drawn to it, while the head actually swings away from it, sending the ship back to the middle of the channel. This suction into the bank is caused by the Venturi effect, that is, the reduction of pressure in the flow between ship and bank. However, this pressure reduction is not uniform along the length, but actually decreases from bow to stern. This sucks the stern in closer, pushing the bow out. This effect is shown in Fig. 7a. This pressure differential from bow to stern causes the ship to be directionally unstable. While in the center of the channel, any yaw angle will set up a turning moment that will increase the yaw further (Fig. 7b).

Some observations have been made on the behaviors of ships in restricted waters:

1) Approaching the bank at an angle increases the turning force away from the bank, sometimes with such force that it appears to be "rejected" (ref. 6). This holds true for angles up to about 40°, after which the turning force changes to suction. The operator must be aware of this, so as not to overcompensate (ref. 7).

2) This combination of bank rejection and directional instability will cause the ship to steer from bank to bank unless corrected, as shown in Fig. 8.

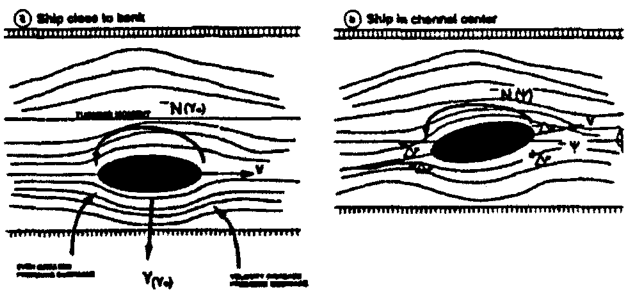


Figure 7
Ship-Bank Interaction (after ref. 1)

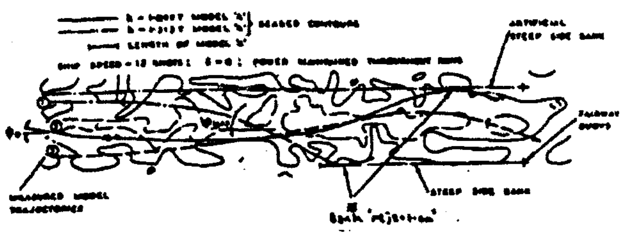


Figure 8
Oscillatory Ship Motion in a Channel (ref. 1)

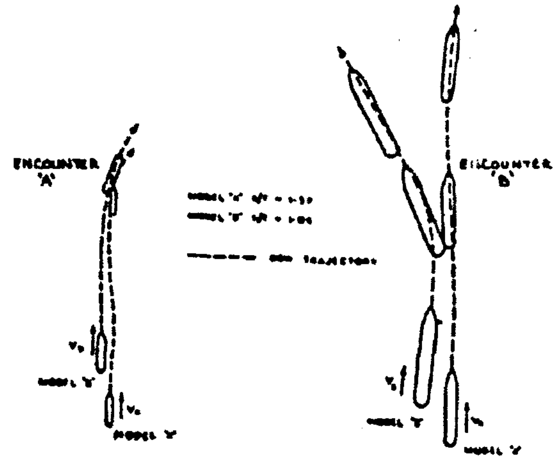


Figure 10
Overtaking Collisions in Shallow Water (ref. 7)

3) These effects are worse for sloped or flooded banks; the operator must be wary of shoals and underwater shelves.

4) The combination of bow-out turning moment and suction side force near the bank can be counteracted by turning the rudder <u>into</u> the bank, which will keep the head in while pushing the ship away.

5) Directional stability will return when the channel is approximately greater than 10 ship widths (ref. 1).

Ship-Ship Interaction

Ship-ship interaction means, of course, collision, or rather the avoidance of it. The most common situations for collision to occur would be during underway replenishment and close convoy operations. Both of these would be overtaking collisions; I will therefore not talk about ship-ship interaction in head-on encounters.

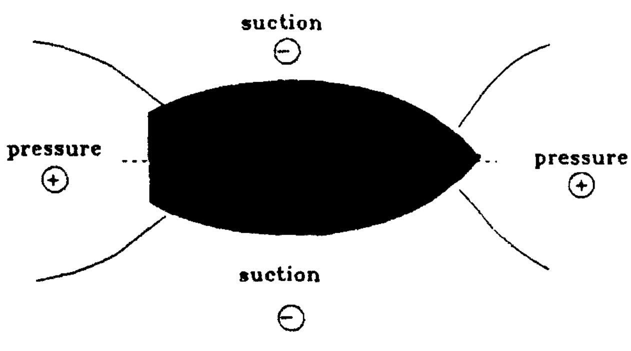


Figure 9
Pressure Field Around a Ship (after ref. 9)

The same hydrodynamic forces that occur near a bank occur between ships, especially when one is much larger than the other. In either deep or shallow water, a ship sets up a pressure field similar to that shown in Fig. 9. In shallow water, this field dies out more slowly than in deep water, so the effects occur over longer ranges.

When two similar-sized ships are running side-by-side, the same suction side force and bow-out turning moment occurs as was the case in ship-bank interaction. The correcting rudder is therefore <u>toward</u> the other ship. However, as one ship overtakes another, the changing pressure fields may cause either the bow to be drawn in, or to be repelled. These two collision types are shown in Fig. 10, where neither ship uses correcting rudder. In encounter 'A' the overtaking ship is drawn into the stern of the other, because the overtaking ship had not drawn ahead enough to develop a bow-out moment. In encounter 'B', the two ships are roughly side-by-side and the bow-out moment is violent enough to swing the stern into the other ship (ref. 7).

The obvious corollary is that operators must be especially careful in any close-ship maneuvering in shallow water, since the pressure effects occur over longer ranges than in deep water.

Crash Stop and Tactical Maneuvering

Both of these actions are generally used to avoid head-on collisions, either with another ship or a stationary object. As with other maneuvers, a ship will behave sluggishly – or worse, erratically. Behaving sluggishly is actually good for a crash stop, but there are other effects.

A twin-screw ship, when putting its propellers astern, will continue in a straight line until it stops. A single screw ship will wear off to one side due to the torque of the

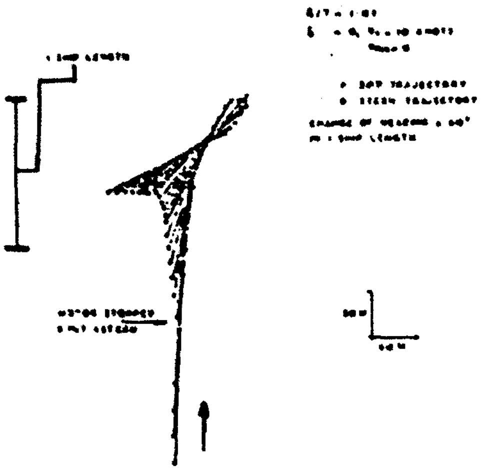


Figure 11
Crash-Stop Trajectory for a Single Screw Ship (ref. 8)

propeller. In shallow water, the twin screw ship (the combatant, say) will slow rather more quickly than in deep water; a good effect. The single screw ship (say, the merchant ship) will not wear away out of its trajectory, but the stern will sidle forward, turning the ship sideways and exposing the ship broadside to th^ collision, as shown in Fig. 11. Unfortunately, the use of helm does little to alter this trajectory (ref. 8). It does stop in a shorter distance, though.

Tactical maneuvering for either single- or twin-screw ships becomes more sluggish, and the tactical diameter increases as depth decreases, in some cases to twice the diameter than for deep water. The obvious corollary is, again, the operator must be much more careful in shallow water.

Overall Maneuvering Considerations

A ship will generally respond more sluggishly in shallow water, and rather anomalous effects occur close to a bank or another ship. I have presented some of the major effects; however, the only way at present to even approximate the shallow-water or restricted-water maneuvering characteristics of a ship is by model tests. Once these are known, operators can be trained in simulators long before they ever take the helm, thus reducing the opportunities for mishaps.

Sinkage and Trim

An important concern in shallow water is the possibility of grounding. Ensuring that the water depth is deeper than the draft is not enough; as explained, ships will experience greater sinkage and trim at speed in shallow water, and then there are fresh-water effects. These will be divided into three areas: 1) behavior over level seabed; 2) behavior over shoals; and 3) fresh-water effects.

Behavior Over Level Seabed

The most obvious effects of shallow water on sinkage and trim are that sinkage tends to increase as depth decreases, and the ship tends to squat by the stern as the speed increases. This last effect is more noticeable on fine-form warships; full-formed ships do not trim as much with increasing speed (ref. 11). However, as stated previously, the ship tends to 'level out' as $V/\sqrt{gh}$ approaches unity. This is important for faster. smaller ships.

The effect of initial trim is quite important. An initial trim by stern invariably means a deeper squat in shallow water, ensuring that the stern would be the first to touch bottom, damaging the propeller. A level trim, or trim by the head, is much more preferable. Maneuvering, starting and stopping all affect sinkage and trim; for example, full-form ships tend to sink and trim more while accelerating than at constant speed, or than while decelerating (ref. 10).

While these effects are complex, reference (10) gives a theoretical method for predicting steady-state sinkage and trim at various speeds and depths, which shows good correlation with model results. Either this theory, or model experiments, may be used to provide "Go/No-Go" curves for the ship's operator. An example is shown in Fig. 12. These, as the name implies, give the conditions of speed and depth where the ship is likely to ground due to sinkage or trim, for various initial drafts and trims.

Behavior Over Shoals

The most dangerous aspect of operating over shoals is the tendency of the ship's extremities to move towards a sandbank while approaching and leaving it (ref. 11). This results in a dynamic response as the ship moves over a shoal, as shown in Fig. 13. As you can see, the bow is initially attracted to the shoal, then violently repelled as the

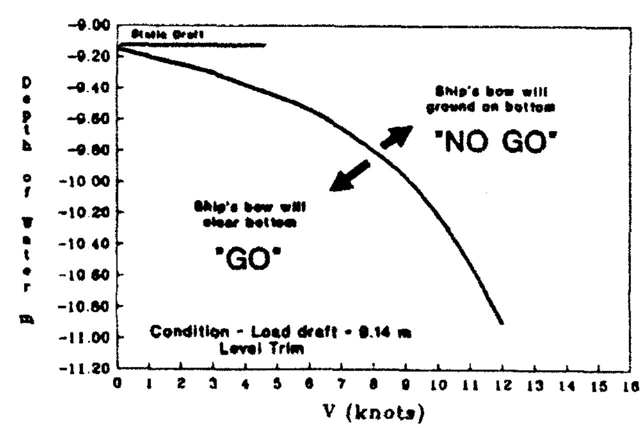


Figure 12
Example of a "Go/No-Go" Curve for Grounding (after ref. 10)

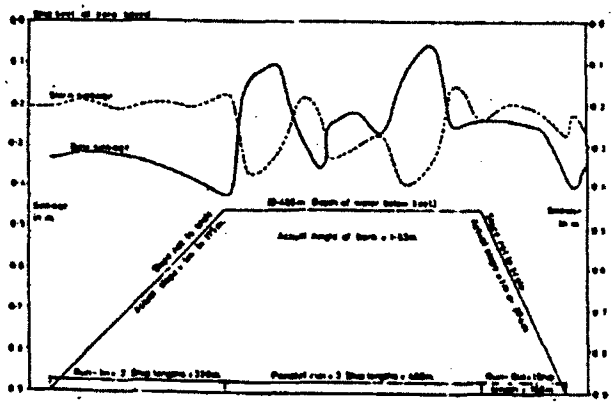


Figure 13
Transitory Response of a Ship Over a Shoal (ref. 11)

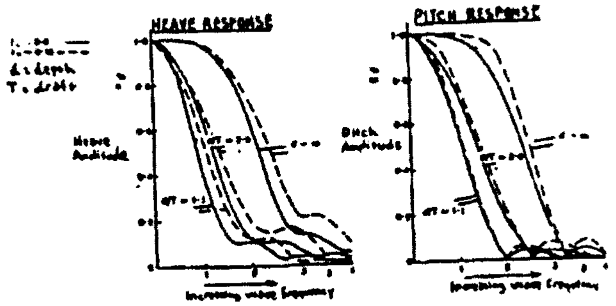


Figure 14
Heave and Pitch Response in Shallow Water (ref. 2)

shoal levels off. This is a similar response to the bank rejection phenomena explained in the section on maneuvering. This transient response causes an overshoot of the steady-state trim for the same depth, thus increasing the possibility of grounding. The obvious corollary is that the "Go/No-Go" curves must be applied very carefully in regions of uneven seabeds.

One interesting observation from Fig. 13 is the tendency of the ship to nosedive as it approaches the shoal. If either the operator or his instruments can sense this among the ship's other motions, it may serve as an alarm to bottom irregularities (fathometers are generally located around amidships, so do not register what the bow will see).

Fresh Water Effects

As shown in Annexe C, a typical estuary condition of half seawater, half fresh water would increase draft about 1.5%, or about 1/2 ft. for a 35 ft. draft container ship. This effect, though small, must be taken into account when operating in extremely shallow water.

Ship Motions

In general, reduced water depth provides a cushioning effect, decreasing the heave and pitch amplitudes of a ship, and reducing its roll period. However, as ship speed increases for a particular depth, the heave and pitch amplitudes increase, and the roll period increases (ref. 12). Sway, surge and yaw are also affected by water depth, but these are comparatively unimportant in shallow water operation.

The effects of water depth and forward speed on heave and pitch are shown in Fig. 14, for a typical fine-form ship in head seas. As you can see, the amplitudes of response decrease considerably as the depth/draft ratio decreases. The dotted curves show that, for a given depth, the amplitudes increase as speed increases. Reference (12) gives the theory for predicting these responses in shallow water, using a source-panel method. These results can be incorporated in a seakeeping program to predict the motions in various depths of waters, headings and speeds.

The most significant finding from this is, of course, the limiting operating depths to avoid grounding. These limiting depths must be based on a combination of the pitch and heave motions in the specific sea state, the shallow-water sinkage and trim (from the "Go/No-Go" curves mentioned earlier), and any fresh water effects. By considering these three factors (and any coupling effects between them), the operator can be given a series of curves telling him or her the minimum operating depths for specific speeds, sea states, and trim conditions.

Other Effects

Confined water operations affect many areas of ship operations, in addition to the ones mentioned. Some of the more important effects are:

Ship vibrations are magnified

No one has yet provided a solid explanation for this, but it appears that the vibrating hull radiates pressure waves which bounce off the bottom and return, sometimes in a reinforcing phase. It has been reported that people can detect shoal water through this magnified vibration (ref. 2). This may affect detectability underwater.

Underwater acoustics are affected

The variations in depth and salinity found in shallow and restricted waters, in addition to varying bottom conditions, make sound performance much less reliable than in

deep water. A good example of this is the repeated failure of the Swedish Navy to find submarines in relatively small, shallow search areas.

Underwater shock effects are increased

Part of the shock wave travels down; in shallow water it is reflected upward fairly quickly. Since the explosion creates a pulsating shock wave, in a certain water depth, with a certain standoff, the initial and reflected waves may reinforce each other.

Fouling of inlets may increase

In shallow water, mud, silt and plant life may be kicked up by the passing ship and ingested into the sea chests, which can affect the condensers, evaporators, firemains, and other seawater-based systems.

Hull fouling may increase

Shallow water usually means an increase in plankton, barnacles, etc. which will foul the hull much more quickly. On the other hand, a large decrease in salinity may kill them off.

CONCLUSIONS

Confined water operations affect the behavior of ships in sometimes unexpected ways, which can present considerable difficulties to ship drivers who are not used to it. Ships move more slowly than in open water – except when they move more quickly. They will maneuver in unexpected ways. Interaction between ships becomes more treacherous. Even when the charts show enough water under the keel, the motions of the ship over shoals can cause an unexpected grounding.

As stated in the Introduction, this paper attempts to point out some of these pitfalls. Hopefully, the methods presented here may prove useful in predicting ship performance. Especially now, when more Navy operations occur close to shore or in gulf regions, it should be used as a guide when considering how ships behave in confined waters.

REFERENCES

[1] Comstock, Principles of Naval Architecture, SNAME 1968

[2] Saunders, Hydrodynamics in Ship Design, Vol. I Ch. 35, SNAME 1964

[3] Ibid, Vol II. Ch. 61

[4] Millward, "Shallow Water and Channel Effects on Ship Wave Resistance at High Sub-Critical and Super-Critical Speeds", Trans. RINA 1983 Vol. 125

[5] Harvald, "Wake and Thrust Deductions at Extreme Propeller Loadings for a Ship Running in Shallow Water", Trans. RINA 1976 Vol. 118

[6] Dand, "On Ship-Bank Interaction", Trans RINA 1982 Vol. 124

[7] Dand, "Hydrodynamic Aspects of Shallow Water Collisions", Trans. RINA 1977 Vol. 119

[8] Dand, "Some Aspects of Maneuvering in Shallow Water", 10th ONR Hydrodynamics Symposium 1979

[9] Rawson & Tupper, Basic Ship Theory Vol. 2, Longam 1984

[10] Dand, Fergusen, "The Squat of Full Ships in Shallow Water", Trans. RINA 1974 Vol. 116

[11] Dand, et al. "Experimental Investigation of Grounding on a Shoaling Sandbank", Trans. RINA 1983 Vol. 125

[12] Inglis, Price, "Motions of Ships in Shallow Water", Trans. RINA 1980 Vol. 122

Annexe A

Calculation of Shallow Water Resistance by Schlichting's Method, as Modified by Landweber to Include the Effects of Restricted Waters (from ref. 1,3).

This method is useful for calculating shallow water resistance at subcritical speeds only. It has been extended to include the effects of restricted waters. Although not a theoretically rigorous solution, to provides fairly accurate results for a complete problem.

The method requires the ship's speed-resistance curve, with the frictional resistance line broken out. (Note that only the resistance increase is calculated; the effects of shallow water on propeller loading, wake fraction, the far powering are not calculated).

The steps are shown in Fig. A1. Essentially, for a given speed/depth ratio (in unrestricted waters), the intermediate wave speed V_I is calculated, and based on the square draft/depth rating the actual shallow-water speed V_h is calculated. The resistance at the intermediate wave speed is plotted graphically, and extrapolated to the actual shallow-water speed. By doing this for a number of speeds, the shallow-water resistance curve is plotted.

The method for calculating resistance in restricted water is handled on the same set of graphs. For calculating speed reduction only, a contour plot was developed for quick estimations.

V_I is the intermediate wave speed, which is the speed of a wave in water depth h. Now, for a given wavelength L, in deep water,

$$V_\infty{}^2 = gL/2\pi$$

In shallow water, this equation is modified to

$V_I{}^2 = [gL/2\pi] \times tanh(2\pi h/L)$, or substituting,

$$V_I = V_\infty \sqrt{\tanh(gh/V_\infty{}^2)} \qquad \text{Eq. A1}$$

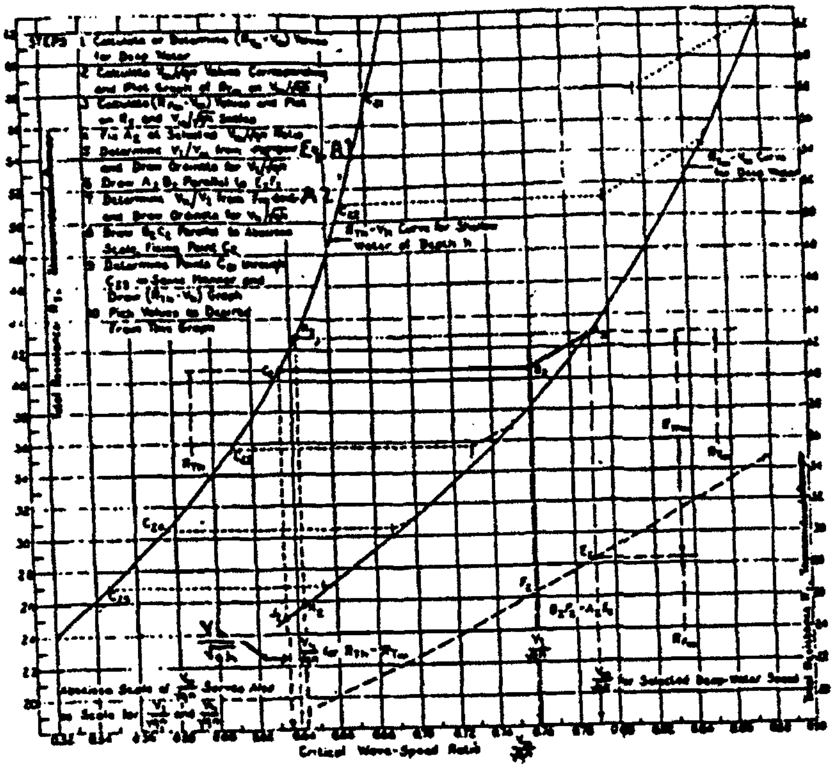


Figure A1
Calculation of Shallow-Water Resistance by Schlichtings's Method (ref. 3)

where

V_∞ = deep water speed

V_I = intermediate wave speed

V_h = shallow water speed

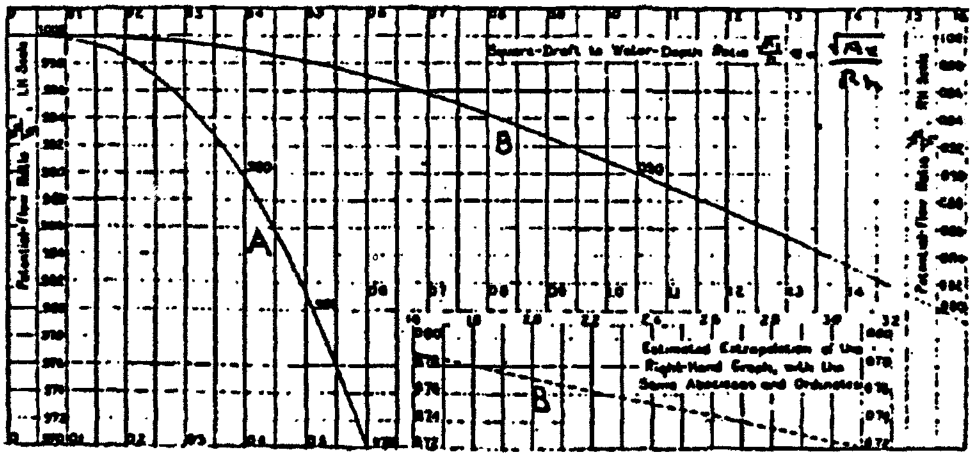


Figure A2
Potential-Flow Ratio V_h/V_I to square draft/depth ratio (ref. 3)

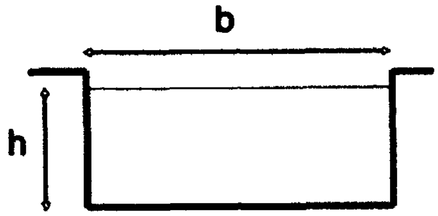
<u>where</u>

A_x = max. midship area
= $B*T*C_x$
h = depth
Rh = hydraulic radius (Eq. A2)

NOTE: Curve 'A' is a magnification of curve 'B', and uses left-hand scale

Extension of Method to Restricted Water

This retains the major features of Schlichting's method, but instead plots V_h as a function of $\sqrt{A_x}/R_h$ (Fig. A2), where R_h is the hydraulic radius of the channel, defined below. The curve is the same for both, since the hydraulic radius acts as an "equivalent depth" for open shallow water.



$$R_h = \frac{\textit{area of cross-section of channel (minus ship)}}{\textit{total wetted perimeter}}$$

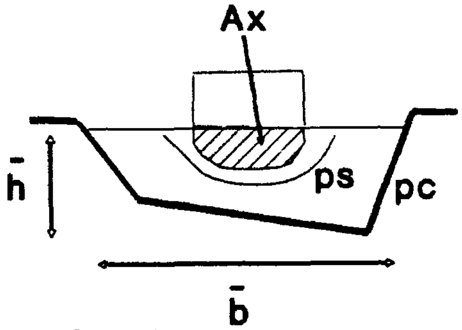
For a square channel with no ship,

$$R_h = \frac{bh}{(b + 2h)}$$

Note that when $b \to \infty$, $R_h \to h$, or the equation reduces to that for shallow open water.

For a channel of irregular cross-section with a ship, the equation becomes:

$$R_h = \frac{\overline{bh} - Ax}{ps + pc} \qquad \text{Eq. A2}$$



where
b = average channel width
h = average channel depth
Ax = midship area
ps = wetted girth of ship
pc = wetted perimeter of channel

The method is the same as described, only using the ratio $\sqrt{A_x}/R_h$ in Fig. A2 for plotting the potential flow ratio V_h/V_I.

Calculation of Speed Loss in Shallow Water

If all that is required is the calculation of speed loss, a very quick estimation may be obtained by using Fig. A3. This is a contour plot at percentage speed reduction as a function of $\sqrt{A_x}/h$ and V_∞^2/gh. The plot can also be used to estimate the speed loss in restricted waters, by substituting the value $\sqrt{A_x}/R_h$ for $\sqrt{A_x}/h$. This plot does not reflect the additional corrections made by Landweber, so there will be some discrepancy between results obtained by this method and the method previously outlined. However, for the example given in reference (1), this discrepancy was only about 2% of speed, or 2/10 of a knot at 10 knots.

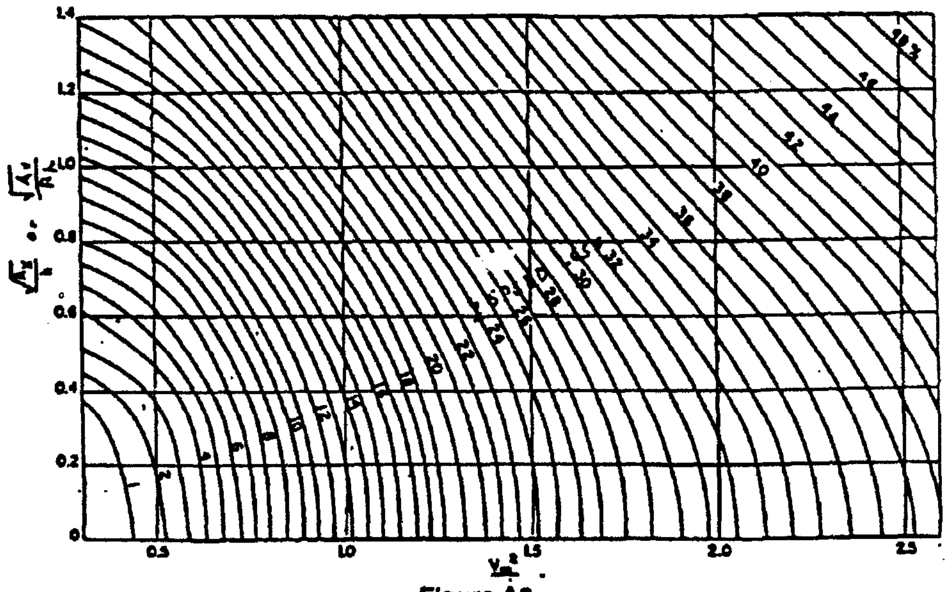


Figure A3

Schlichting's Chart for Calculating Speed Loss in Shallow Water (ref. 3)
(Total loss given in percentage reduction, i.e., Vh = (%loss)*V∞*100)

Annexe B

Equations for Calculation of Wavemaking Resistance in Shallow Water by Millward's Method (from ref. 4).

This method is based on the linear wavemaking resistance theory developed by J. Michell in 1898, and extended to both shallow and restricted water cases by A. Millward in 1981 (based on the work at Strettensky and Kirsch, as referenced in his papers). This annexe only presents the equations and simplifying assumptions used; the actual application must needs be done by computer, as it involves integration over a body surface and various nasty iterative solutions.

Required input:

L = ship length	H = water depth
B = ship beam	K = channel width
T = ship drag	F = ship Froude number $V/\sqrt{gL}$
e,g	F_h = depth Froude number $V/\sqrt{gH}$

For deep water,

$$R^*_\infty = \int_{\gamma_0}^{\infty} \frac{(\gamma/\gamma_0)^2 J^2_\infty}{[(\gamma/\gamma_0)^2 - 1]^{1/2}} d\gamma \qquad \underline{\text{Eq. B1}}$$

where

$$J_\infty = \int_0^1\int_0^1 \frac{\partial\eta}{\partial\xi} e^{-\theta\rho}\sin(\gamma\xi)\, d\xi\, d\rho \qquad \underline{\text{Eq. B2}}$$

For shallow water,

$$R^*_h = \frac{L}{4}\int_{\bar\gamma_0}^{\infty} \frac{\bar\gamma J^2_h}{[\bar\gamma^2 - (\bar\gamma^2/F^2L)\tanh(\bar\gamma H)]^{1/2}\cosh^2(\bar\gamma H)} d\bar\gamma$$

Eq. B3

where

$$J_\eta = \int_0^1\int_0^1 \frac{\partial\eta}{\partial\xi} cosh[\bar\gamma(H - T\rho)]\,\sin[L/2\,\xi((\bar\gamma/F^2L)\tanh(\bar\gamma H))^{1/2}]\, d\xi\, d\rho$$

Eq. B4

For $V < \sqrt{gH}$, $\bar\gamma_0$ determined by $\tanh(\bar\gamma_0 H) = (V^2/gH)\,\bar\gamma_0 H$

which is calculated iteratively. When $V > \sqrt{gH}$, $\bar\gamma_0 = 0$ ($\bar\gamma$ is the integration variable of $\bar\gamma_0$)

For restricted waters,

$$R^*_c = \frac{\pi L}{2K}[J^2_0 + 2\sum_{n=1}^{\infty} J^2_\eta] \qquad \underline{\text{Eq. B5}}$$

where

$$J_\eta = \int_0^1\int_0^1 \frac{\frac{\partial\eta}{\partial\xi}\cosh[\bar\gamma_\eta(H - T\rho)]\sin[L/2\,\xi((\bar\gamma/F^2L)\tanh(\bar\gamma H))]^{1/2}}{[(1+(4\pi^2\eta^2/K^2\bar\gamma^2_\eta))\cosh^2(\bar\gamma^\eta H) - 1/\bar\eta^2]^{1/2}} d\xi d\rho$$

Eq. B6

and $\bar\gamma_\eta$ is the solution (calculated iteratively) of:

$$(1/F^2_\eta)\tanh(\bar\gamma_\eta H) = H[\bar\gamma_\eta - (4\pi^2\eta^2/K^2\bar\gamma_\eta)]$$

$$J_0 = J_\eta \text{ where } \eta = 0;\ \text{for } V > \sqrt{gH}, J_0 = 0$$

In all cases, the R^* is the non-dimensional wave resistance; the actual wave resistance is given by:

$$R_w = R^*(8/\pi\, eg\frac{B^2T^2}{L})$$

<u>Nomenclature</u>

$\gamma_0 = 1/2F^2$ $\quad\gamma$ = integration variable of γ_0
ξ = nondimensional x−coordinate $x/(L/2)$
η = nondimesional y−coordinate $f(x,z)/(B/2)$
$\theta = 2T/L \times \gamma^2/\gamma_0$
J = integral over surface

<u>Simplifying Assumptions</u>

1. Ship symmetrical fore-and-aft, side-to-side
2. Rectangular cross-section thoughout (i.e., z = T, ρ = 1)
3. Parabolic waterlines (i.e., $\eta(\xi) = 1 - \xi^2$; $\frac{d\eta}{d\xi} = -2\xi$)

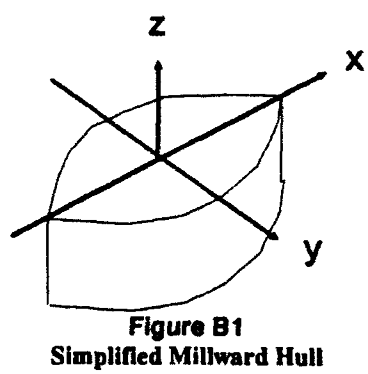


Figure B1
Simplified Millward Hull

4

Annexe C

Reduction of Frictional Resistance Due to Fresh Water Effects

This is a sort of "handwaving argument" to calculate the approximate order of magnitude that frictional resistance is reduced by influx of fresh water into estuaries, deltas, bays, channels and other confined waters that ships may operate in.

Assume that a typical estuary will have a half and half mixture of fresh and salt water (in real life, this varies across the board). Therefore, we get the following values (in metric):

	Fresh	Estuary	Salt
e (kg/m^3)	996	1010	1025
ν (m^2/sec)	1.134×10^{-6}	1.163×10^{-6}	1.188×10^{-6}

Since the displacement remains the same, i.e., $e_{sw}\nabla_{sw} = e_{est}\nabla_{est}$ the change in displaced volume ∇_{sw}/∇_{sw} is approximately e_{sw}/e_{est}; therefore, the change in wetted surface is $(e_{sw}/e_{est})^{2/3} = (1025/1010)^{2/3} = 1.010$

For a typical value of $R_n \approx 10^9$ in salt water, the change in kinematic viscosity ν gives
$R_{n\,est} = R_{n\,sw}\ \nu_{sw}/\nu_{est} = 10^9(1.188/1.163) \approx 1.021\times10^9$

Using the 1957 ITTC Line for frictional resistance, the C_f for salt water $= 0.075/(\log_{10} 10^9 - 2)^2 = 1.530\times10^{-3}$ and the C_f for estuary water $=$
$0.075/(\log_{10} 1.021\times10^9 - 2)^2 = 1.526\times10^{-3}$

$$\text{so, } \frac{R_{est}}{R_{sw}} = \frac{\tfrac{1}{2}(1010)V^2(1.010\,s)(1.526\times10^{-3})}{\tfrac{1}{2}(1025)V^2\ \ s\ \ (1.530\times10^{-3})}$$

$$R_{est} = .992\,R_{sw} \quad (R = \text{resistance})$$

or less than 1% reduction in frictional resistance.

(Note that the effect on draft would be $\dfrac{e_{sw}}{e_{est}} = \dfrac{1025}{1010} = 1.015$, or 1.5% increase.)

THINK ENERGY AGAIN !
A VIDEO ENHANCED SECAT PROGRAM

Hasan Pehlivan
Propulsion Systems Analysis Division
NAVSEA 56X11
Naval Sea Systems Command

April 1991

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of the Department of the Navy.

ABSTRACT

During the mid 1980's, due to the fossil fuel glut and low energy cost, many energy conservation programs were shelved. The NAVSEA's Ship Energy Conservation Assist Team (SECAT) program, which was a successful and proven program, is an example of this. Details on the original SECAT procedures, implementation and benefits were contained in a paper presented at the ASE 20th Symposium in 1983 and carried in ASNE Journal of March 1984. Also, the Guide for Energy Conservation, NAVSEA SL101-AA-GYD-010, provides SECAT energy savings opportunities aboard naval ships. The SECAT program was cancelled due to low fuel costs and budget constraints in the late 1980's.

Recent events in the middle east have caused fuel prices to increase dramatically and it is not clear at what level they will stabilize. Also, the developments in the eastern european countries allow the world now to get more involved with the most urgent problems that our planet is facing such as environmental pollution and energy. These situations require us, the Navy community, to re-evaluate our position and put more emphasis on energy conservation again. Thinking along this line, as a member of SECAT, I developed a "Video Enhanced SECAT" program.

Although SECAT has been demonstrated to be a powerful program for energy savings aboard U.S. Naval Ships, it was labor intensive. It was taking about 3 months from initial data collection to completion of the report for each ship. From 1981 through 1987, 34 ships have received SECAT. Also, SECAT was tailored to steam ships only. Therefore, a new program is needed which would provide the same benefits as SECAT, yet be implemented to all naval ships more rapidly and effectively. The "Video Enhanced SECAT" program will fulfill this goal.

The video training concept, with the advancements in the electronics technology, is becoming powerful tool for getting the message to an audience more effectively, quickly and repeatedly. In fact, several training programs already being implemented aboard ships by using the ship's closed circuit TV systems. Therefore, this technique will be an effective way to train the ship crews and to implement energy conservation on all Navy Ships.

This paper will discuss new techniques to develop SECAT Videos for each ship class (steam, gas turbine and diesel); streamlining the original SECAT procedures; integration of the SECAT with other TYCOM audit programs such as PEB for feedback and repeatability; and institutionalize SECAT Video Training into Ship Navy Training Schools, on board training, and Navy Training Plans.

OBJECTIVE

Provide energy conservation training, monitoring and related improvements to U.S. Navy ships by enhancing previously proven SECAT program techniques with video presentations, state-of-the-art monitoring, and energy/reliability assessments.

BACKGROUND

NAVSEA recognized the need to reduce ship fuel consumption and established the Ship Energy Conservation Assist Team (SECAT) pilot program in 1981. Because of the limited pages allowed for this paper, I will refer the readers for the details on the SECAT procedures, implementation and benefits to the following documents: The technical paper presented at the ASE 20th Symposium in 1983 and carried in ASNE Journal of March 1984 and the Guide for Shipboard Energy Conservation, NAVSEA SL101-AA-GYD-010.

Since 1981, 34 ships received SECAT. In 1986, due to low oil prices and budget constraints, the SECAT was stopped.

A 1

SECAT achieved immediate success on steam ships by reducing fuel consumption as documented in Appendix A. The program results, however, degraded over time due to crew changes, lack of follow-up visits, and lack of integration with the ship's day-to-day maintenance, training and inspection efforts. Recognition of these factors along with the realization that budgets will be reduced in the future, points out the need to revive an improved SECAT program to conserve fuel and reduce steaming hours. Video-based training has been added to institutionalize the savings methodology.

DISCUSSION

SECAT was demonstrated to be a powerful program for reducing fuel consumption aboard U.S. Naval vessels, however it was labor intensive. It took about 3 months from initial data collection to completion of the report for each ship. Since the Navy is entering a period of reduced budgets without a corresponding reduction of commitments, improved fuel consumption must be achieved. The original SECAT program, however, may be too expensive to provide its benefits on a fleet wide basis.

A program, which could provide the same benefits as SECAT and be implemented into the fleet more rapidly and effectively, is needed. Such a new program should also provide institutionalized training to ensure continuity of energy awareness and a means to assess long-term results. Its goal should be to provide the operator with the means to make energy conservation decisions in light of real time environmental and operational scenarios without compromising availability or survivability. This new program is discussed in Appendix B and summarized in the following sections. Its technical contents and methodology are the same as the initial SECAT program with the implementation by video cassette recording (VCR) in lieu of a written report, and incorporation of modern data collection and analysis. It will incorporate the relevant experience of other energy conservation programs designed to assist those trying to maintain operational commitments in an atmosphere of declining resources.

The video training concept has become a very powerful tool for getting a message to an audience efficiently, quickly and repeatedly. Every ship visited by SECAT teams had a VCR and was using it to enhance its normal training programs. This technique is an effective way to train the ship crews and can be used to implement energy conservation for all Navy ships on a recurring basis. Follow-up visits will be provided to assess the effectiveness of the training and to gather data that will allow quantitative evaluation of fuel usage for comparison to energy consumption goals.

The program will include a survey of other NATO navies, commercial shipping operators and other organizations to determine if there are other energy conservation and monitoring techniques in use that may be of potential benefit to the U.S. Navy.

PROGRAM IMPLEMENTATION

Appendix B provides description of the each major efforts. It also includes a Figure 1 which shows a Plan of Action and Milestones (POA&M) for the Video Enhanced SECAT Program.

In general, the program will define the basic scope of the effort required for a given ship class and provide video based training and monitoring of representative steam, gas turbine and diesel ships.

The first year will represent an evaluation period during which results from a worldwide energy survey and experience from ship surveys conducted using video-based training will be documented. Following the initial evaluation period, an assessment will be made and adjustments will be incorporated as indicated to further enhance the fuel savings potential on a fleet-wide basis.

The program will require annual reassessment to establish priorities in pursuit of long-term goals. The long term goals projected for this program are as follows:

- Develop ship class videos and documentation consistent with projected service lives and potential for energy savings.
- Distribute videos and documentation to all ships of subject classes, as soon as accepted by Navy.
- Document the relationship between energy conservation techniques and ship Reliability, Maintainability and Availability (RMA).
- Institutionalize SECAT Video Training into Navy Training Schools, on board training, Navy Training Plans, etc.
- Continue ship surveys on a spot check basis each year. Eventually transfer this function to TYCOMS as part of their normal inspections and reviews, such as the Propulsion Examining Board (PEB).
- Develope an incentive plan which would return to ships forces a share of the cost savings due to energy conservation.

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- Establish an NAVSEA Energy Award Program to enhance shipboard energy awareness and to provide added incentive.

- Develop a R&D effort to provide the operator with P.C.-based Energy Management System (EMS) to assist in making real time decisions based on environmental and operational factors. The elements of the envisioned R&D effort are described by Appendix C.

BUDGET

The program would include two stages. The first stage would involve a three year program implementation period. Its estimated cost is as follows:

	FY 91	FY 92	FY 93
I. Baseline Definition	$50K	–	–
II. Provide Training			
IIA. Develop Video & Initial Training*	$60K x 2	$60K x 3	$60K x 5
IIB. Additional Training**	$ 5K x 8	$ 5K x 12	$ 5K x 20
III. Document Results	–	$20K	$20K
IV. Program Assessment & Adjustments	–	$50K	$50K
Totals	$210K	$310K	$470K
* Assume 2 ship classes 1st year, 3 classes 2nd year and 5 classes 3rd year.			
** Assume a additional ships per class/year			
Total cost for 3 year period			$ 990K
Estimated Initial Savings (First 2 years) +			$16,800K
+ (Assuming 30 to 1 savings per year from Appendix A)			

The second stage of the program would include indoctrination of the ships determined to have sufficient remaining service life to make the expenditure worthwhile. It is estimated that the average annual cost to indoctrinate approximately 25 additional ships into the program and to monitor those already in the program.

SUMMARY

Energy conservation is a direct method of increasing the operational readiness of the fleet. Previous SECAT efforts demonstrated that energy conservation could be successfully implemented in the fleet, but follow-up is needed to ensure that the results do not degrade. The video enhanced SECAT Program will accomplish this goal.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Messrs. Ken Kenyon and Dennis Breen of AME, Inc. for their valuable comments, ideas and cost estimation.

APPENDIX A

SECAT PROGRAM BENEFITS

The potential fuel savings by implementing SECAT energy conservation initiatives, and consequent increased operations, are shown in the table below. This data is obtained from References 1 through 4. The annual fuel saving estimates vary depending on the ship size and mission. For example, USS FANNING (FF 1076) has the potential of saving 10,289 barrels each year; the USS SEATTLE (AOE 3) can save 21,549 barrels each year. These fuel savings correspond to increased operations of 8,820 nautical miles or 39 days for FF 1076 and 16,162 nautical miles or 75 days for AOE 3.

POTENTIAL ANNUAL FUEL SAVINGS				
	SAVINGS		RETURN ON INVESTMENT	
	Fuel BBL/Yr	$/Yr $35/Yr	Average Invest($)	Savings/ Invest
AOE 3 (Ref.1)	21,549 (*)	754,215	20,625	36.5
DDG 13 (Ref.2)	14,400 (**)	504,000	8,130	62.0
CG 32 (Ref.3)	10,535 (**)	368,725	12,222	20.2
FF 1076 (Ref.4)	10,289 (**)	360,115	6,815	52.8
(*)Fuel savings based on annual operating hours with estimated speed time profile from FY 1981 and 1982 NEURS fuel consumption data. Representative Speed-Time Profiles for AOEs are provided for both east and west coast AOEs by Reference 5.				
(**)Annual operating hours from speed time profile provided by Reference 6.				

The Return on Investment is based on $35 per barrel for SECAT savings and the average per ship investment required for a ship class of the proposed Video Enhanced SECAT assuming $60K for video and initial ship training and $5K for training each of the other ships of the class. It shows that if every ship in the AOE 1 class and the CG 26 class is surveyed, they could save the cost of the investment, in approximately two weeks operating time. The DDG 2 class and FF 1052 class can pay off in approximately one week.

Benefits gained by the SECAT program can be demonstrated by the following examples:

In May 1984, Messrs. C. W. Kenyon and H. Pehlivan performed a SECAT visit aboard USS WILLIAM H. STANDLEY (CG 32). A visit to another ship in San Diego in 1985 provided the opportunity for the above persons to revisit the CG 32. The executive officer and chief engineer of CG 32 were very enthusiastic about the benefits of the SECAT program. They indicated that when STANDLEY transited from Panama to San Diego, they were able to reduce fuel consumption by 38 percent by following SECAT recommendations for selecting the most economical transit speed and efficient machinery alignments. Some other examples of the reception to SECAT from ship operators are shown below:

USS CONYNGHAM: "As a result (of SECAT) significant fuel savings were achieved without sacrificing mission capability."

USS PHARRIS: "Another important factor contributing to lower fuel consumption...SECAT has been an invaluable tool in identifying and correcting energy wasting practices."

USS JESSE L. BROWN: "Beneficial to enlighten department awareness toward energy efficiency."

USS BARNEY: "Unlike some other assist visits I've had...SECAT was an excellent help in making BARNEY aware of procedures and plant alignments that can maximize fuel conservation."

USS SAMUAL GOMPERS: "Good idea. We have received some good information. This program should be pushed to save fuel and money."

USS KING: "Thorough, helpful. Will be used a great deal for future planning. EMMO spoke highly of group from his experience on RICHARD E. BYRD."

USS FANNING: "Outstanding...establishes curves/awareness."

USS PENSACOLA: "Very useful...fuel savings should enable additional training days at sea."

Other information on SECAT procedures, implementation and benefits are described in various technical papers such as the one presented at the ASE 20th Symposium, 1983 and carried in ASNE Journal of March 1984.

SECAT recommendations are expected to provide annual fuel savings of over $2 million for CV 59/60 class ships, $3 million for LHA 1 class ships and $4 million for BB 61 class ships based on predictions of the STMSYS Energy Balance Computer Program. See References 7 through 11.

APPENDIX B

VIDEO ENHANCED SECAT PROGRAM PLAN

PURPOSE: To define the management plan necessary to implement the Enhanced SECAT Program.

BACKGROUND: See page 2.

DISCUSSION: See page 2.

ASSIGNMENT OF RESPONSIBILITIES:

- NAVSEA 56X1 Lead Code
- DTRC/R&D Support
- TYCOM Support
- Contractor Support
- Individual Ships

PROGRAM IMPLEMENTATION: Introductory discussion of program schedule (Figure 1) and lead-in for task description of the major tasks.

Phase I: Baseline Definition

The purpose of this task is to define the scope of the program consistent with NAVSEA, TYCOM and individual ship needs and desires. It will result in specific identification of the content of all training and monitoring techniques to be employed. Specific subtasks are as follows:

- SUBTASK I-1: World-wide Energy Conservation Technique Survey. This subtask will survey other NATO navies, merchant marine operators, power industries and other relevant organizations to determine the current practices regarding energy conservation and monitoring techniques. These will be reviewed for application to U.S. Navy ships. This will ensure that new techniques are considered for incorporation in the Enhanced SECAT.

- SUBTASK I-2: TYCOM and ship visits. It is necessary that the end user, the TYCOM and individual ships, have input to the program's definition. These visits will ascertain their needs and

recommendations and will make the fleet more receptive to the Enhanced SECAT Program.

- SUBTASK I-3: Survey SECAT Ship. This task will survey a ship that had previously received a SECAT visit for the purpose of determining whether any of the benefits from the previous program are still evident. This will permit a program decision to be made regarding the number and classes of ships to be included in the program.

- SUBTASK I-4: Define Baseline. This subtask will provide a plan nominating ship classes, ships to be surveyed during first three years and representative steam, gas turbine and diesel ships for an initial evaluation period. The plan shall be approved by senior NAVSEA management.

Phase II: Provide Video Tape and Training

II-A: Initial Ship Training

This phase will consist of at-sea visit and training for shipboard personnel on fuel saving techniques by use of video cassette recordings. It will cover representative steam, gas turbine and diesel powered ships. The initial training for the ship selected to represent its class will include the following elements:

Development of a standard Video Tape and Documentation (one per class)

A video tape, applicable to all ships within a given class, will be developed based on the results of world-wide energy survey (subtask I-1) and the NAVSEA Energy Guide (Reference 12) which will include the following:

- Fuel measurement by using sprayer plate capacity curves for steam ships, fuel meters for gas turbine and diesel ships.

- Discussion of machinery alignments.

- Discussion of fuel curve development for various machinery alignments.

- Discussion of sample fuel curves showing fuel savings obtainable by use of different machinery alignments.

- Discussion of optimum transit speed fuel curves showing fuel savings obtainable by use of different machinery alignments.

- Discussion of sample calculations to determine fuel savings by using optimum transit speed.

- Listing of applicable energy conservation tips.

Energy Conservation Documentation developed to supplement the Video Tape will include the following:

- A standard ENERGY TIPS plate per class to be posted in places such as Pilot House, Main Control, and Mess Area.

- A standardized Energy Survey Check List for each class to be completed by SECAT.

- A standardized fuel consumption curves plate based on NAVSEA Fuel Economy Trials to be posted in Pilot House, Main Control and engineering spaces as applicable.

- A software package to be used for development of fuel curves by ships personnel using a PC.

- A standardized Questionnaire for each class to be answered by each ship force during survey.

Ship Visit

The training for the program will be provided by a visit to a selected ship. This will include the following:

- Send advisory, with Video Tape, to ship prior to visit.

- Conduct Pre-Briefing and orientation.

- Complete the Questionnaire & survey check list.

- Conduct Post Brief: Discuss survey findings (good and bad), present Energy Tips Plates, Fuel Curves Plates, Questionnaires, and Check list assembled in a package.

II-B Additional Ship Training

The ship visit outlined for Initial Ship Training will be repeated for the other ships in the class.

Phase III: Document Results

Approximately one year after the initial ship visit for each of the representative ships, the ship will be revisited for the purpose of documenting a representative ship's experience with video-enhanced SECAT. The visit will audit ship's records and observe normal operations to ascertain whether the program has been integrated into normal shipboard training, evaluations and procedures. Fuel

consumption will be checked to determine actual savings resulting from the enhanced SECAT techniques.

Phase IV: Program Assessment & Adjustments

This effort will assess all program results to this point and incorporate findings from the worldwide energy survey and first year SECAT survey experience into a revised program plan designed to improve the effectiveness of shipboard energy conservation techniques. The purpose will be to refine the direction of the effort for fleet-wide incorporation.

APPENDIX C

ENERGY MANAGEMENT SYSTEM R&D PROGRAM

A potential R&D program is envisioned which could be integrated into the Enhanced SECAT program at some future date. It would provide an Energy Management System (EMS) for each ship, which is a tool for the ship's command to use to monitor shipboard energy usage and predict fuel usage for specific operations.

The Chief Engineer and senior engineering department personnel would use the analytical capabilities provided by EMS for the evaluation of propulsion cycle efficiency and the efficiency of ancillary equipments associated with the propulsion plant, electrical plant, hotel services, combat systems, communications, etc. EMS should have performance graphics capabilities able to provide performance curves such as fuel consumption and equipment efficiencies under a variety of operating conditions. It should reflect environmental conditions, equipment degradation, maintenance, reliability and availability in association with efficiency, energy conservation and finally fuel savings for a given operational scenario.

Another factor which should be incorporated into the program is the required condition of readiness. Properly used EMS could optimize fuel consumption, predict fuel usage and resulting range predictions based on available fuel in tanks for missions and mission changes. Thus, not only a tool to save energy but one which manages fuel for ship operations.

Estimates of the development time or cost of EMS will be provided at some future date. It should be reviewed with DTRC prior to attempting to put numbers to the elements of this initiative. However, it is envisioned as a long-term goal associated with the enhanced SECAT program.

FIGURE 1
VIDEO ENHANCED SECAT POA&M

PROGRAM ELEMENTS	FY 91	FY 92	FY 93
PHASE I: BASELINE DEFINITION			
1. Survey World-Wide Energy Ideas	s— — — ^		
2. Visit Tycom	s— — ^		
3. Survey A Secat Ship	s— —- ^		
4. Define Baseline And Select Representative Steam, Diesel And Gas Turbine Ships	s--- ^		
PHASE II: PROVIDE TRAINING			
1. Develope Video For Ship Class (10)	s---- ^ -- ^	-- ^ ------ ^ ----- ^ ------	^ --- ^ --- ^ ---- ^ --- ^
2. Conduct Ship Visit & Initial Training	s--- ^ ------	' --- ^ ---- ^ ----- ^ ----	-- ^ --- ^ --- ^ --- ^ -- ^
3. Distribute Videos To Other Ships In Class	s--- ^ -----	^ -- ^ ----- ^ ----- ^ ----	-- ^ --- ^ --- ^ --- ^ -- ^
4. Provide Training For Other Ships In Class	s--- ^ ----	- ^ --- ^ ---- ^ ---- ^ ---	-- ^ --- ^ --- ^ --- ^ -- ^
PHASE III: DOCUMENT RESULTS			
1. Follow-up Visit To Rep Stm Ship		s------ ^	
2. Follow-up Visit To Rep Diesel Ship			s------ ^
3. Follow-up Visit To Rep Gt Ship			s-- --- ^
PHASE IV: PROGRAM ASSESSMENT & ADJUSTMENTS			
1. Present Results To Navsea			s------ ^
2. Navsea Review The Results			s------ ^
3. Make Adjustments As Directed			s------ ^
s = start, ^ = complete			

LIST OF REFERENCES

[1] NAVSEA Report, "Ship Energy Conservation Assist Team (SECAT) Visit to USS Seattle (AOE 3)," February 1983.

[2] NAVSEA Report, "Ship Energy Conservation Assist Team (SECAT) Visit to USS Hoel (DDG 1)," March 1985.

[3] NAVSEA Report, "Ship Energy Conservation Assist Team (SECAT) Visit to USS William H. Stundley (CG 32)," August 1984.

[4] NAVSEA Report, "Ship Energy Conservation Assist Team (SECAT) Visit to USS Fanning (FF 1076)," September 1984.

[5] NAVSEA Report, "Representative AOE Speed-Time Profiles" June 1985.

[6] NAVSEA Association of Scientists and Engineers paper, "Fuel Savings for Cruisers and Destroyers Utilizing Electric Vice Steam Driven Pumps," By R. Dangel, C. Kenyon and H. Pehlivan, 1983 Technical Symposium.

[7] DTNSRDC-PASD-CR-17-84, USS Forrestal (CV 59) Shipboard Energy Conservation Analysis, DTNSRDC, Annapolis Laboratory, August 1984.

[8] DTNSRDC-PASD-CR-6-84, USS Saratoga (CV 60) Shipboard Energy Conservation Analysis DTNSRDC, Annapolis Laboratory, February 1984.

[9] DTNSRDC-PASD-CR-13-85, USS Independence (CV 62) Shipboard Energy Conservation Analysis, DTNSRDC, Annapolis Laboratory, September 1985.

[10] DTNSRDC-PASD-CR-14-85, USS Iowa (BB 61) Class Shipboard Energy Conservation Sensitivity Analysis, DTNSRDC, Annapolis Laboratory, July 1985.

[11] DTNSRDC-PASD-CR-1-87, LHA and LPH Classes Shipboard Energy Conservation Sensitivity Analysis, DTNSRDC, Annapolis Laboratory, November 1986.

[12] NAVSEA Publication SL101-AA-GYO-010, Guide for Energy Conservation (Fuel Economy), Shipboard Application, 31 January 1985.

QUALITY SHIP SERVICE POWER WITH AN INTEGRATED DIESEL ELECTRIC PLANT

Thomas C. Dalton
Electrical Engineer
Electrical Systems SubGroup
Ship Service Electrical Systems
Surface Ships
(SEA 56Z11)
Naval Sea Systems Command

April 11, 1991

Approved for Public Release
Distribution Unlimited

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ABSTRACT

For smaller auxiliaries and T-ships the predominate choice of power for ship propulsion and ship service generation is diesel AC generator sets and DC motors fed from SCR rectifier drives. All integrated diesel electric AC generation/DC propulsion ships have long endured an inherent power quality problem due to harmonic feedback from their power electronics equipment, which transforms the fixed voltage and frequency power of the generator into a speed controllable format of DC voltage at the motor for variable speed/power in ship propulsion. This paper defines the basic harmonic issue for shipboard applications by reviewing the primary sources of harmonics, available design methods for addressing harmonics, industrial standard practices and analytical guidelines on harmonics and shipboard experience and design approaches concerning harmonics. The best means of achieving power quality compatibility between ship service generation and propulsion electrical power requirements are explored according to their benefits and limitations/penalties and recommendations for future ship designs are presented.

FIGURES

TABLES

ABBREVIATIONS

AC	alternating current
A_N	voltage notch area
C	capacitance
cos	cosine function
D	distortion or harmonic power
DC	direct current
DF	distortion factor
E_s	system or generator source AC voltage
E_d	average DC voltage of rectifier under load
E_{do}	average DC voltage of rectifier at no load
E_x	direct DC voltage drop from commutation reactance
h	inductance in henries
H[n,t]	amplitude value of harmonic periodic function in phase voltage or current at frequency n or time t
I	current
K	multiplier of 1000
L	inductance
M	multiplier of 1,000,000
m	multiplier of .001
n	whole integer numbers
p	phase quantity of a power system or device
P	real or actual power
PC Ratio	propulsion power to clean power ratio
PU	per unit base value of a power system or device
q	pulse quantity of a power system or device
Q	imaginary or reactive power
R	resistance
RF	Reactance Factor (commutation reactance/ load or source reactance)
S	total or apparent power
SCR	silicon controlled rectifier
SC Ratio	short circuit capacity to SCR drive power ratio of a power system
sin	sine function
SW[t]	generic sinewave function
$SW[t]_{ph}$	phase voltage or current sinewave power function
t	time in degrees or seconds
T	torque
THD	total harmonic distortion power
u	multiplier of .000001
V	voltage
W	wattage
X	reactance in terms of capacitance or inductance
X_d	generator subtransient reactance
Z	impedance
Z Ratio	total system impedance to a common point impedance (typically Z Ratio = $Z_S/(Z_S + Z_L)$)
ω	angular speed
Φ	magnetic flux
μ	commutation angle
α	firing delay or phase control angle of SCR
ϕ	conduction separation angle between SCR phases
π	value of 3.14 or 180°
θ	angle between voltage and current
δ	sum of commutation and phase control angles

INTRODUCTION

HARMONICS: DEFINITIONS, SOURCES AND EFFECTS

Before the late 1940's there were very few nonlinear consumer loads (radios, televisions and fluorescent lights) and industrial loads (AC to DC, DC to AC or AC to AC frequency conversion devices or thyristors versus motor/generator sets) on their respective electrical distribution systems. Nonlinear loads are essentially those types of devices that alter the shape of the current waveform from the basic sinusoidal voltage waveform that is provided by the power source (see Figure 1). With the advent of transistors, silicon controlled rectifiers (SCR's) and similar solid state switching devices in the late 1940's, the loading from nonlinear electronic equipment and motor loads supplied through power electronic devices has begun to significantly dominate the overall loading spectrum. The ever increasing impingement of the undesirable nonlinear load effects on the consumer and industrial electrical systems were finally realized in the 1970's and have now achieved their due respect in the 1980's.

Harmonic waveforms are composed mathematically as a specific portion of a basic periodic time dependent sinewave function, which is defined by the following Fourier Series expression (where n = 1,2,3,4,etc. and C_o, K_c and K_s are constants for zero offset and amplitude values for cosine and sine functions, respectively):

$$SW[t] = C_o + (K_c)(1/n)(\cos n\omega t) + (K_s)(1/n)(\sin n\omega t)$$

For rectifiers k = nq + 1 or nq-1, which primarily addresses the most significant harmonics or characteristic harmonics.

The three phase rectifiers develop characteristic harmonics (fundamental frequencies above the pulse quantity) that add to the original AC power system sinewave. The resultant summation is defined by the following Fourier Series expression, which is based on a phase (p)

TABLE 1 [1,2,3]
HARMONIC SOURCES

ELECTRICAL DEVICE	SOURCE OF PHENOMENA	TOTAL HARMONIC* (%PU) + +
Transformer	core magnetization +	1
Fluorescent lighting	ballast magnetization +	5-30
Generator or motor (synchronous/ induction)	core magnetization + slot winding effects	2
Motor (universal)	current switching, slot winding effects, core magnetization +	5
Motor** (direct current)	current switching, core magnetization + slot winding effects	5
Frequency converters (rectifier or invertor)	current switching	20-30
Electronics (power supplies)	current switching	10-20

* no filtering
** DC system effect only
\+ eddy and inrush currents, magnetic flux saturation and hysteresis effects
\+ + %PU in reference to device not system

TABLE 2 [1,2,3]
HARMONIC EFFECTS

ELECTRICAL EQUIPMENT	TOTAL HARMONIC LEVEL (%PU) +	EFFECTS
Generators, transformers, flourescent and incandescent lighting, motor, cabling	10 10 2	overheating, reduced efficiency, reduced service life, increased noise/vibration (rotating torque pulsations), increased reactive power requirements or equipment size/rating, lighting flicker*, high voltage failure of insulation (especially in capacitors and windings)
Electronics	9-12	high voltage failure of power supplies (especially in coils and capacitors), overheating of power supplies (especially in coils and resistors) special/additional power supply filtering, errors in clock timing functions

* light intensity variation
\+ %PU in reference to device not system

or pulse (q) relationship (q = 2 x p or two times the phase value to account for negative and positive sides of the sinewave waveform)(where n = 1,2,3,4, etc.):

$$SW[t]_{ph} + H[t] = ((2 \times (3)^{1/2})/\pi\ ) (K_c) \times$$

$$(\cos \omega t + (1/(nq+1)) \cos (nq+1)\omega t + (1/(nq-1)) \cos (nq-1)\omega t)$$

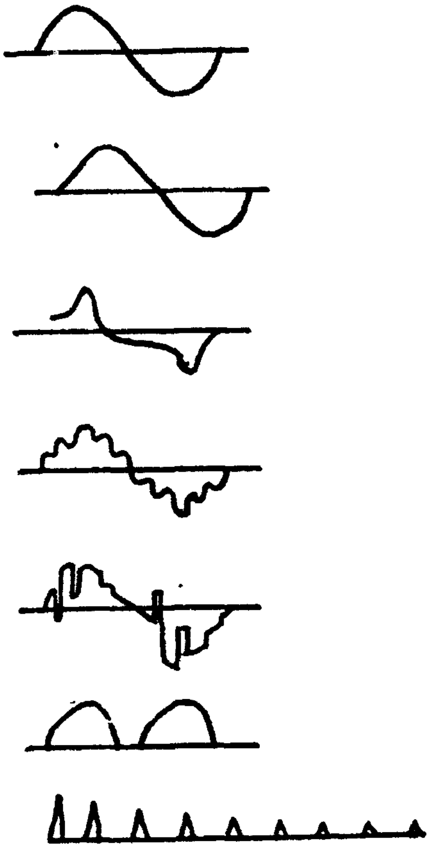
The following magnitude terms of total harmonic distortion (THD) or distortion factor (DF) are the summation of such values with respect to the fundamental for defining the total harmonic level (where k = 1,2,3,4,etc.):

$$\text{THD}\ \% = 100 \times (\Sigma H[k]^2)^{1/2}/H[1]$$

$$\text{or} \quad DF = (\Sigma H[k]^2/H[1]^2)^{1/2}$$

For rectifiers k = nq + 1 or nq - 1, which primarily addresses the most significant harmonics or characteristic harmonics.

Industry has realized that the electrical equipment depicted in Table 1 exhibit nonlinear current characteristics, which translate proportionately into voltage harmonics from the electrical system impedance (resistance plus inductance and capacitance) relationship via ohms law ($V = I \times Z_{R,L,C}$). If there was no impedance relative to the harmonic current, there would in turn be no voltage drop as a result of that current. In effect, the harmonic voltage distortion becomes negligible. This in essence actually occurs when harmonic filters are employed because they effectively short circuit (provide at least a 10:1 ratio between power system and filter impedances) the harmonic current back to its source. This localized short circuit action of filtering occurs without affecting the remaining power system voltage substantially. Essentially a nonlinear load acts as a power conditioner (frequency converter) that transposes some of the fundamental sinewave form into selected higher order multiple harmonic frequencies of the fundamental depending on the particular transformation phenomena of that equipment load. Table 1 and Figure 1 [1,2,3,4,5] delineate the typical electrical equipment that produce harmonics,



SINUSODIAL VOLTAGE - AC FULL WAVEFORM

SINUSODIAL CURRENT - AC FULL WAVEFORM

TRANSFORMER CURRENT - AC FULL WAVEFORM

GENERATOR CURRENT - AC FULL WAVEFORM

SCR DRIVE VOLTAGE - AC FULL WAVEFORM

DISCONTINUOUS VOLTAGE - DC FULL WAVEFORM

TRANSFORMER INRUSH CURRENT
WAVEFORM DISTRIBUTION

TYPICAL WAVEFORMS

FIGURE 1

the phenomena that creates these harmonics and the levels and waveforms of harmonics usually associated with those equipment.

From Table 1 it can be seen that as long as frequency conversion, electronics and fluorescent lighting loads are much smaller than the generating capacity, the harmonic content in the power system will be dominated by the synchronous/induction motors and generators. Transformers are not large harmonic contributors even if a significant portion of the load requires such power conditioning. Significant electronic loads in commercial buildings (computers for instance) can be the predominate harmonics contributor despite the fluorescent lighting load. The inherent 2% value shown for rotating machinery is partially why MIL-STD-1399 and MIL-G-3124 must adopt greater values of 3% and 5% for maximum individual and total harmonic distortion levels to define Type I power and generator characteristics for a total power system and generator design, respectively. Total harmonic levels of 5% to 10% are also typically encountered and assumed in commercial practice unless significant nonlinear loads are serviced.

The adverse effects of harmonics are numerous as reflected in Table 2 and can be summarized as increased maintenance and repair costs in general. Typically the reduced performance and/or efficiency translates into higher system costs indirectly through the power function service being provided. One of the more startling effects of harmonics is the shortened service life expectancy of motors and generators by a factor of two that occurs from just a 3% to 5% harmonic level, which corresponds to a temperature rise of 25%.[6]

RECTIFIER CHARACTERISTICS

The harmonics of SCR drives are derived from several sources. The primary source is the conduction separation angle (ϕ) between SCR firings and the phase control (firing delay) angle (α). These angles are determined by the pulse quantity of a given SCR drive and the required load demand, respectively (see Figures 2 and 3)[4]. The secondary source is an initial SCR firing phenomena termed the notching effect (AC line voltage collapse due to short circuit inrush current between phases), which occurs from the commutation or shutdown (overlap) angle (u) of two separate SCRs switching simultaneously on and off, respectively, in an overlapping manner as they feed power into a DC load (see Figures 2 and 3)[4]. Both the commutation and phase control angles affect the harmonic level, as either increase so do the harmonics (see Figure 4)[3]. An additional useful trait of SCR drives is the relationship of the power factor (PF) increasing with the increase in pulses (typical minimum PF $= \cos 2\pi/q$ and the maximum PF $= q/\pi \times \sin \pi/q$, see Figure 5[3,4] and Table 3).

COMMUTATION & DELAY ANGLE EFFECTS ON AC HARMONICS

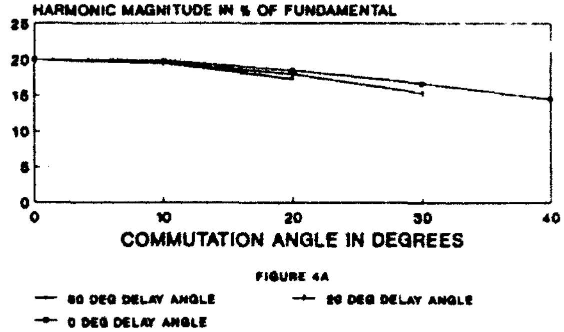


FIGURE 4A

FIFTH HARMONIC

COMMUTATION AND DELAY ANGLE EFFECTS ON AC HARMONICS

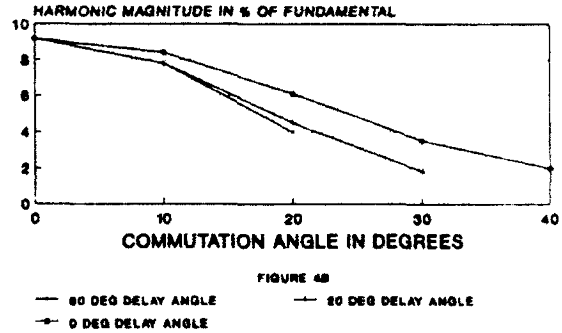


FIGURE 4B

ELEVENTH HARMONIC

POWER FACTOR VS REACTANCE FACTOR
FOR 6 & 12 PULSE RECTIFIERS

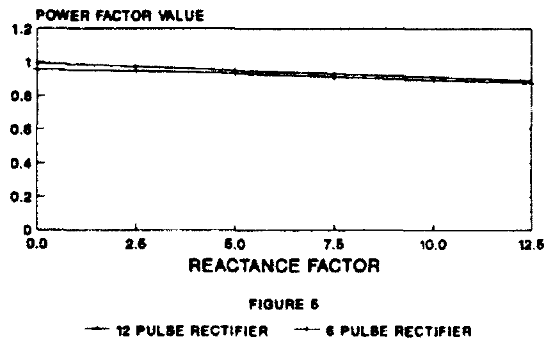


FIGURE 5

LOAD BASED REACTANCE FACTOR

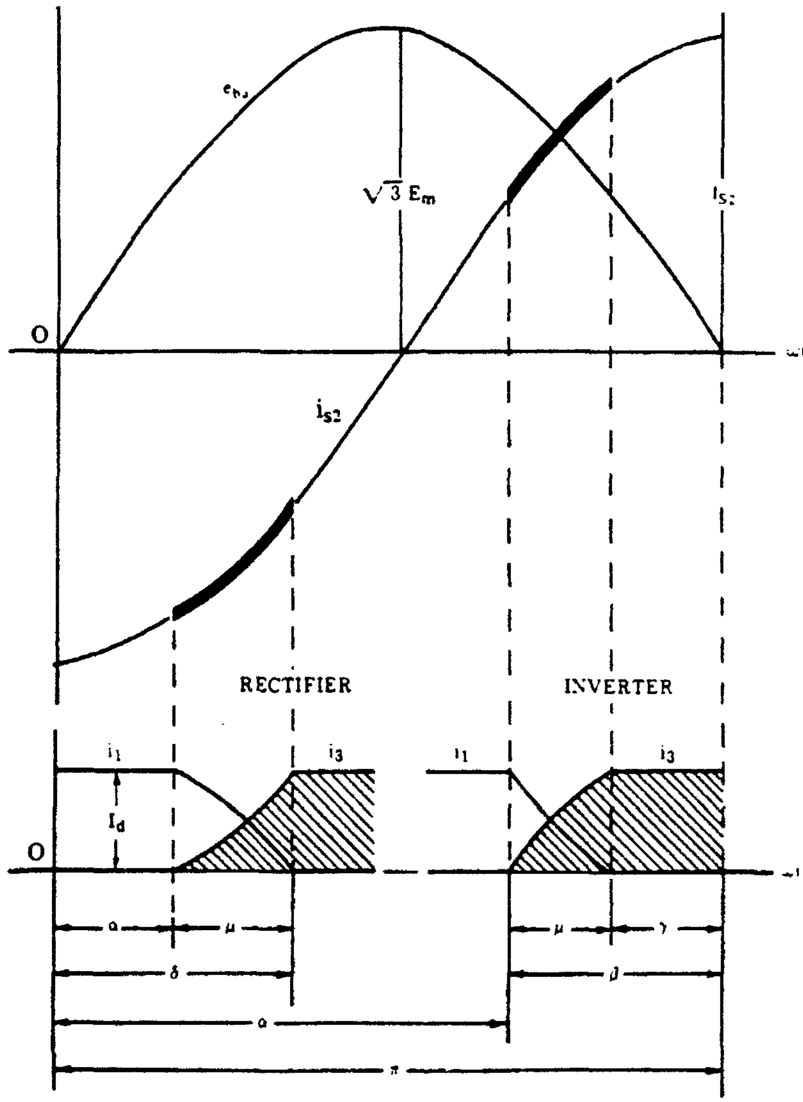
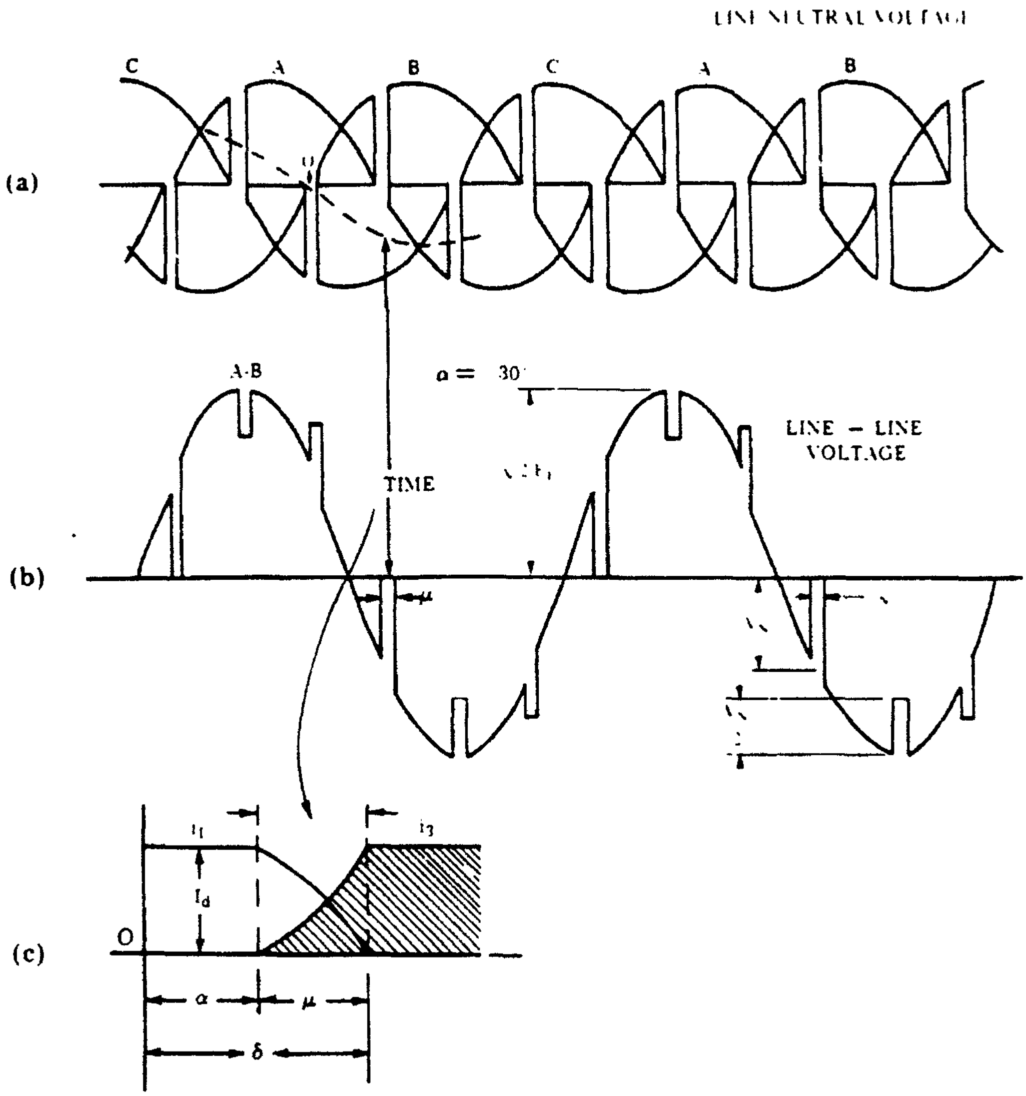


FIGURE 2

Relations Among Angles
Used in Converter Theory



NOTE: The two other phases are similar to A-B. Width of notches is exaggerated and ringing omitted for clarity.

FIGURE 3
Voltage Notches

TABLE 3 [3,4] POWER FACTOR FOR MULTI-PULSE SCR DRIVES		
SCR UNIT PULSES	MINIMUM PF	MAXIMUM PF
6	.500	.827
12	.866	.955
18	.940	.982
24	.966	.988
30	.978	.992
36	.985	.995

The conduction separation angle is basically a function of the number of phase sets or multiple six pulse groups (normally a three phase power source used or six pulses to account for three positive and negative sections of one cycle of a three phase waveform) by the relationship of $\phi = 360^\circ/q$ (for example; 6 = q has $\phi = 30^\circ$, 12 = q has $\phi = 15^\circ$, 24 = q has $\phi = 7.5^\circ$, and 48 = q has $\phi = 3.3^\circ$). The phase control angle varies from 0° to 90° for positive power flow (negative or reverse power flow via invertor function occurs from 90° to 180°). As the phase control angle increases to lessen the load power or voltage/current level; the harmonics will increase, especially if the DC output becomes discontinuous (the phase control angle exceeds twice the conduction separation angle, which is 120° for a six pulse SCR drive (see Figure 1). A six pulse SCR group is the basic building block for SCR drives (see Figures 6 and 7)[3].

The line commutation voltage notching effect, which is like a reverse voltage spike, is a function of the SCR switching speed. Given a specific SCR application, the power source and distribution system inductance primarily control the notching effect since it is basically the fact or results of not being able to shutdown a SCR instantaneously. As such the overlap period of both SCRs simultaneously conducting is essentially a momentary short circuit between two of the AC phases from the power source. Although industry continues to improve SCR technology and their control circuitry for faster SCR switching response, the SCR drive phase power transfer switching will never be an ideal instantaneous transition. On an utility power system the voltage bus is considered relatively firm because the power source and distribution system offer so little inductance that quick voltage changes cannot occur and a notching effect is minimized inherently. If the power system is soft because the power source and distribution system have relatively high inductance, then the notching effect will be more pronounced. Accordingly, the voltage level before the SCR conducts cannot be sustained immediately after switching commutation of the two SCRs. These effects are due to the inability of the power system to withstand sudden short circuit load magnitude changes at constant voltage. If the power system X/R ratio becomes less than six, the voltage notching effect will resonant at about 20 KHz.[6]

TABLE 4 SCR DRIVE DC RIPPLE HARMONIC LEVELS		
HARMONIC ORDER	THEORETICAL (%PU) +	TYPICAL (%PU) +
6	18.0	2.9
12	6.0	0.7
18	2.5	0.3
24	1.3	0.2
30	1.1	0.1
36	1.0	0.1

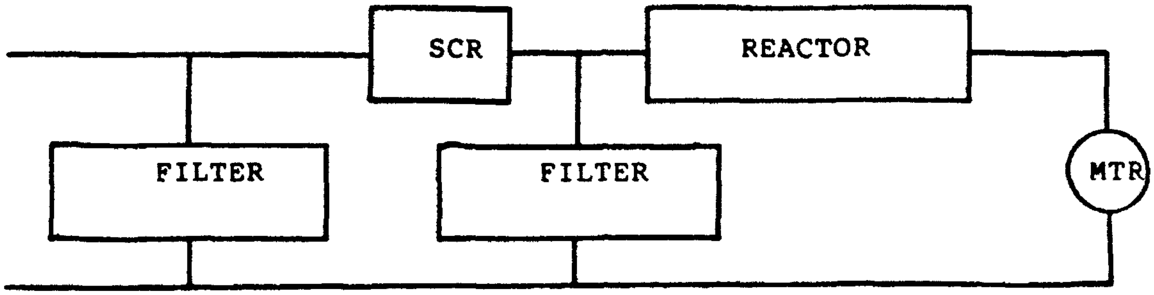
Another more heightened concern for SCR drive users typically is the DC ripple that appears and the resultant vibration (see Figure 8)[3] in the motors. The torque pulsations have a greater effect than realized from the low DC ripple level and constant average torque projected because of their severe oscillatory nature. The typically experienced and theoretical DC ripple magnitudes are represented by the following formal expression (see Table 4)(where n = 1,2,3,4,etc.) and approximated formula:

$H[q] = 200/((nq)^2-1)$ (typically experienced approximation)

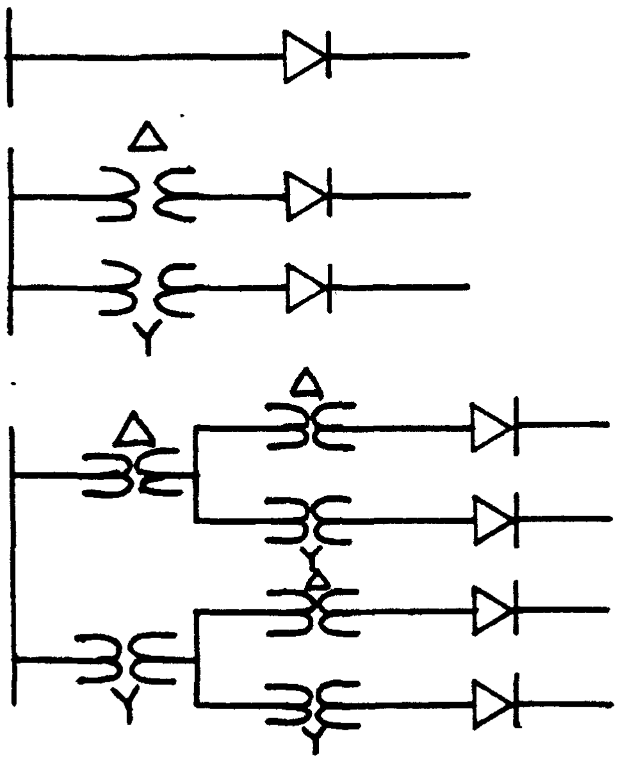
$H[q] = (1/nq)\,H[1]$ (theoretical formal value)

The magnitude of the DC ripple is contingent on the conduction separation angle, phase control angle and commutation angle just like the AC harmonics (see Figures 9, 10 and 11[2,5], including effects of impedance and system imbalances due to phase voltage and impedance differences and varying phase control angles within a SCR group. Figure 9 eludes to the interrelated AC and DC harmonic relationship. To prevent cogging action at very low speeds due to a discontinuous current waveform (see Figure 1), the inductance of the DC load side of the SCR group is raised by series reactors (in line ripple chokes or interphase transformers) to smooth out the DC waveform or inherent ripple harmonics.

In summary, the harmonic content from SCR drives is a function of the quantity or multiple of six pulse groups (see Figure 7) and power source and distribution system inductance. The magnitude of the harmonics dwindle to a relatively low and constant value after about the 48th and 24th order of the fundamental frequency for AC and DC side harmonics, respectively, and are normally considered insignificant beyond that order of fundamental frequency. This is especially true for actually experienced harmonic levels since they are even lower due to the inherent power system filtering effects (see Figures 12 and 13[4] and Table 5). However, some minor level of power



SCR DRIVE/MOTOR CONFIGURATION



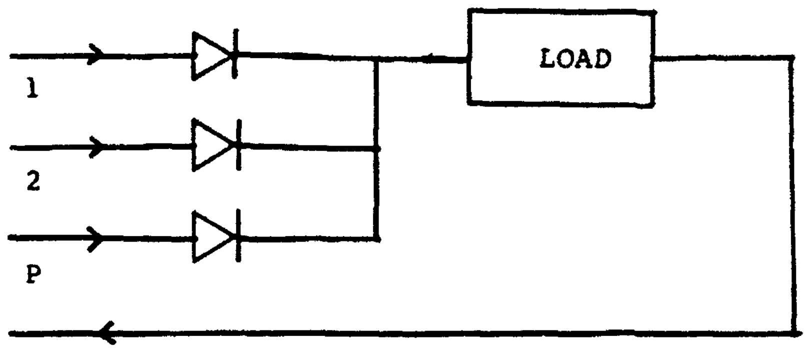
SIX PHASE SCR DRIVE

TWELVE PHASE SCR DRIVE

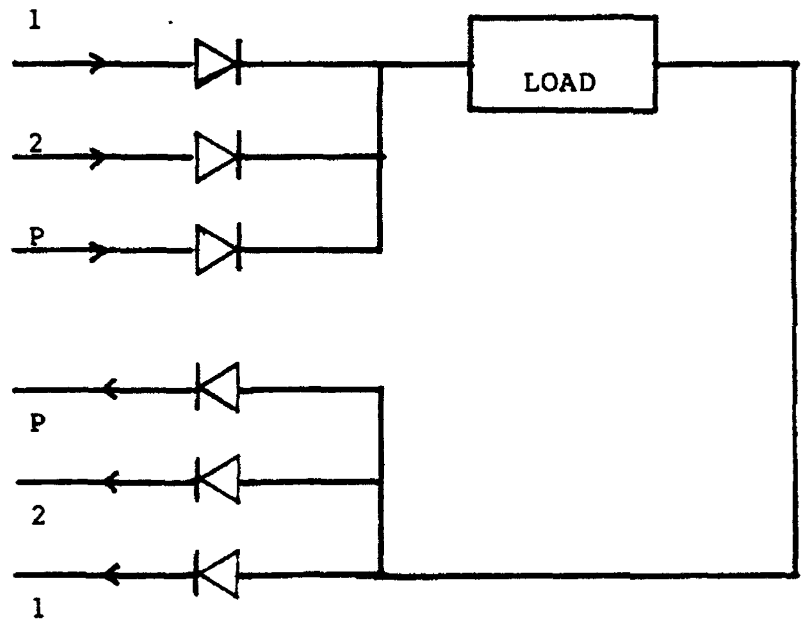
TWENTY-FOUR PHASE SCR DRIVE

SCR DRIVE PULSE CONFIGURATIONS

FIGURE 7



ONE WAY CONVERTER OF P PHASES (3 IN THIS CASE)



TWO WAY CONVERTER OF P PHASES (6 IN THIS CASE)

SCR RECTIFIER CONCEPTS

FIGURE 6

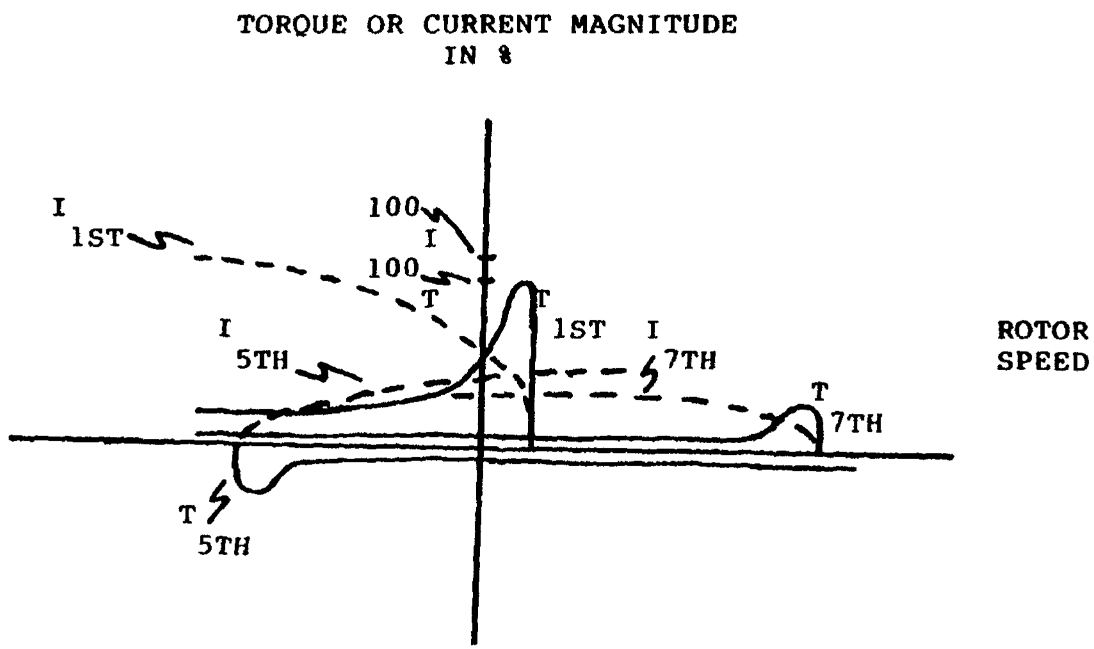


FIGURE 8

DC ROTOR HARMONIC TORQUES AND CURRENTS
(FUNDAMENTAL, 5TH & 7TH)

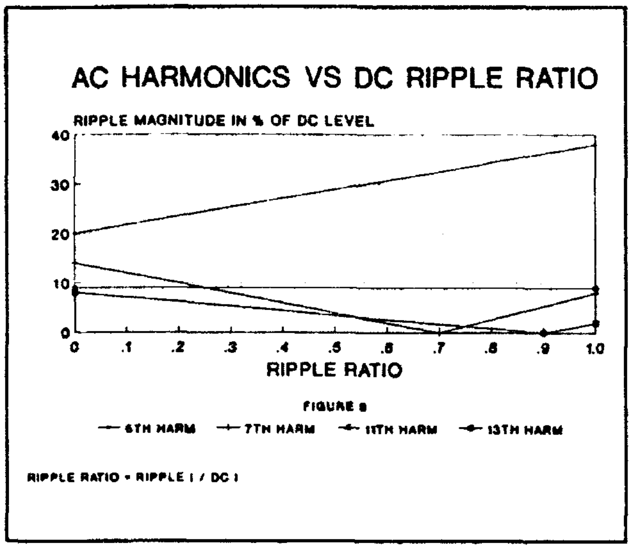


FIGURE 9

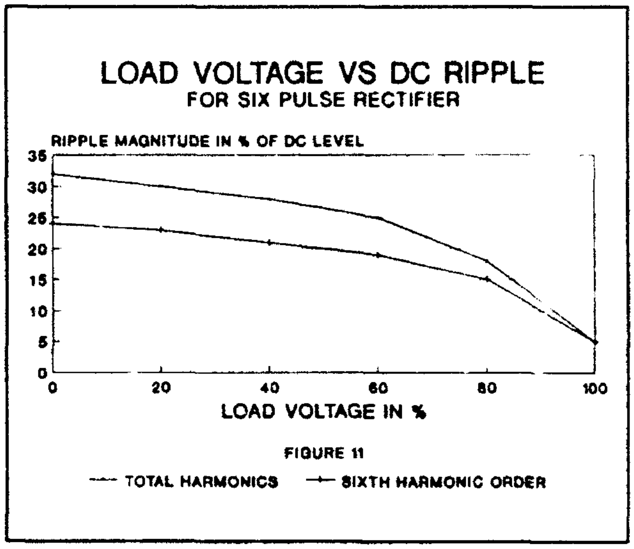


FIGURE 11

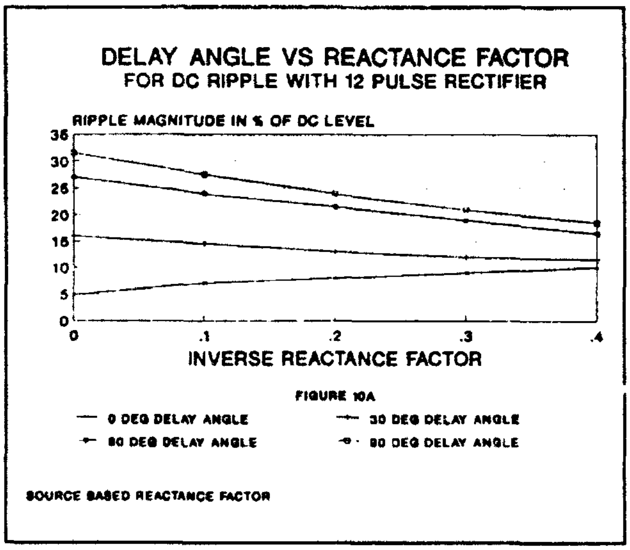


FIGURE 10A

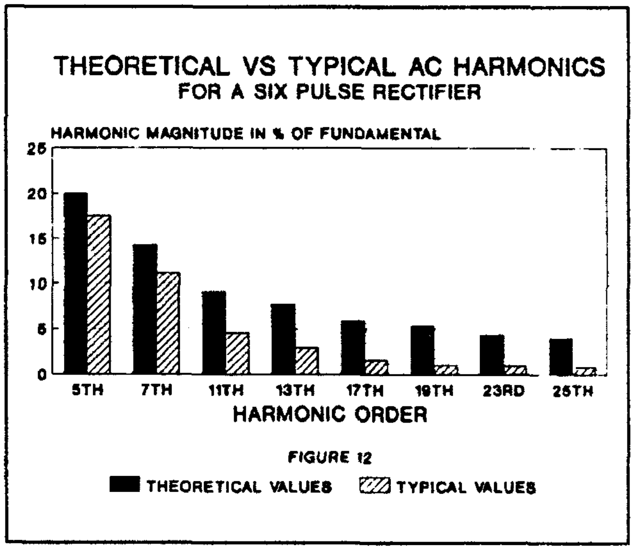


FIGURE 12

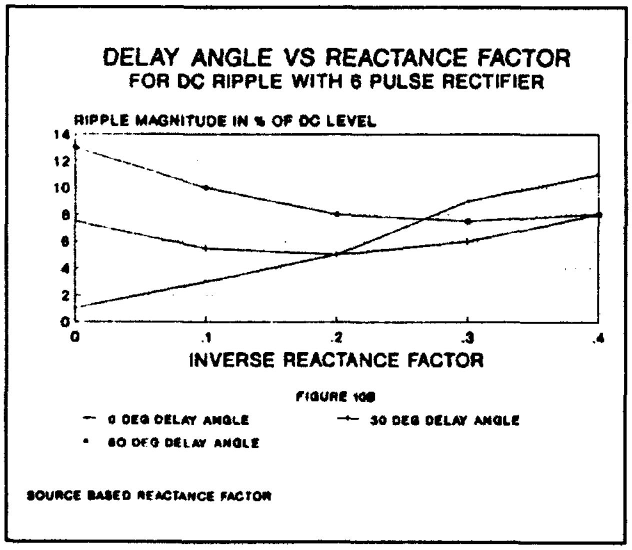


FIGURE 10B

system phase voltage and impedance and phase control angle imbalances occur since no device or system is perfectly balanced. Such conditions increase the AC and DC harmonic level of uncharacteristic fundamental frequencies (all those frequencies below the pulse number of the SCR drive, particularly the third order fundamental frequency and including all even harmonics). Therefore in theory the uncharacteristic harmonics are zero, but in practice the uncharacteristic harmonics are as shown in Table 5 (typically the uncharacteristic harmonics of higher pulse SCR drives are 10% to 30% of the six pulse SCR drive levels).[4,5,6]

TABLE 5 [4]
SCR DRIVE AC HARMONIC LEVELS

HARMONIC FREQUENCY ORDER	THEORETICAL*	ACTUAL PULSE QUANTITY			
	NA (%PU) +	6 (%PU)	12 (%PU)	18 (%PU)	24 (%PU)
1	100.0	100.0	100.0	100.0	100.0
5	19.2	17.5	2.6	2.6	2.6
7	13.2	11.0	1.6	1.6	1.6
11	7.3	4.5	4.5	0.7	0.7
13	5.7	2.9	2.9	0.4	0.4
17	3.5	1.5	1.5	1.5	0.2
19	2.7	1.0	1.0	1.0	0.1
23	2.0	0.9	0.9	0.9	0.1
25	1.6	0.8	0.8	0.8	0.1
29	1.4	NA	NA	NA	NA
31	1.2	NA	NA	NA	NA
35	1.1	NA	NA	NA	NA
37	1.0	NA	NA	NA	NA
41	0.9	NA	NA	NA	NA
43	0.8	NA	NA	NA	NA
47	0.8	NA	NA	NA	NA
49	0.7	NA	NA	NA	NA
TOTAL - THEORY	NA	25.7	21.5	10.6	5.1
TOTAL - TYPICAL	NA	21.5	6.54	3.84	3.42

* Theoretical values are zero below the pulse quantity
\+ %PU in reference to device not system

HARMONIC CONTROL/REDUCTION/ COUNTERMEASURE/ISOLATION TECHNIQUES

The most obvious means of minimizing the harmonic content is addressing the source controlling it since lowering the impedance to reduce the harmonic effect is difficult because of the inherent power system characteristics and only marginally effective. As previously inferred, the lower the conduction separation and phase control angles the lower the harmonics for the SCR drives and the higher the power factor for the power system become. Since such design features make for incremental improvements, the harmonic failure degradation of a six pulse group within the SCR drive is about 6/q of that associated with a typical six pulse group. Multiple pulse group SCR drives create more complex and expensive and possibly heavier and larger SCR drives. Normal practice is now twelve pulse versus six pulse drives, but some twenty-four rather than eighteen pulse drives (an odd multiple of six pulse SCR groups) have become increasingly more common. Because of the minimal time for control and reaction of phasing the SCR, a forty-eight pulse SCR drive or about 3.3° conduction separation angle is about the limit of this technology. Sequential firing of SCRs within a multiple SCR drive is another SCR harmonic reduction method. This method has several parallel SCRs functioning as one overall SCR phase connection or leg to keep phase control angles at minimum levels in most of the SCRs by requiring only one SCR to alter its phase control angle to compensate for the precise power loading demand required (i.e., power is obtained in whole increments from all but one SCR device and by the remaining SCR adjusting its phase control angle to the final required value of power demanded). This approach does require more balanced firing between the parallel SCRs to coordinate a synchronous power output and only addresses the conduction separation angle aspect (a higher SCR pulse configuration reduces the conduction separation angle for lower DC ripple). Both a sequential SCR or a higher SCR pulse approach are particularly sensitive to increasing uncharacteristic harmonics from inherent system phase voltage and impedance and SCR firing angle imbalances due to the ability of those SCR drives to greatly reduce their overall harmonic level. The added depth in SCRs of the sequential SCR concept provides for very incremental failure degradation. Space, weight, complexity and cost impacts of the SCR sequential concept are much more pronounced for a given pulse level than for a standard SCR drive design.

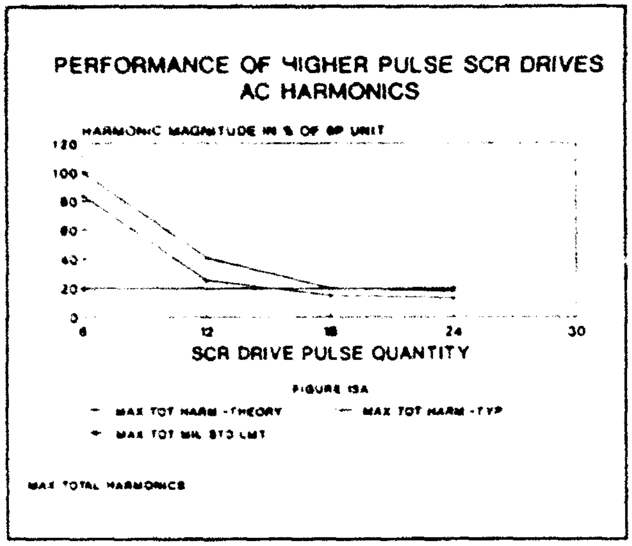


FIGURE 13A

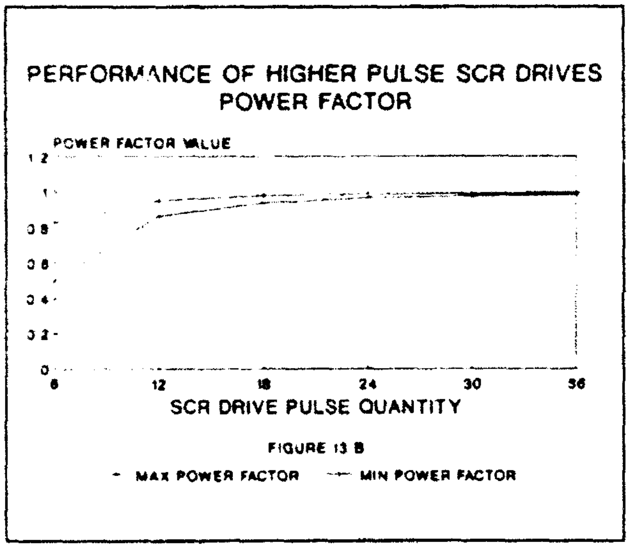


FIGURE 13 B

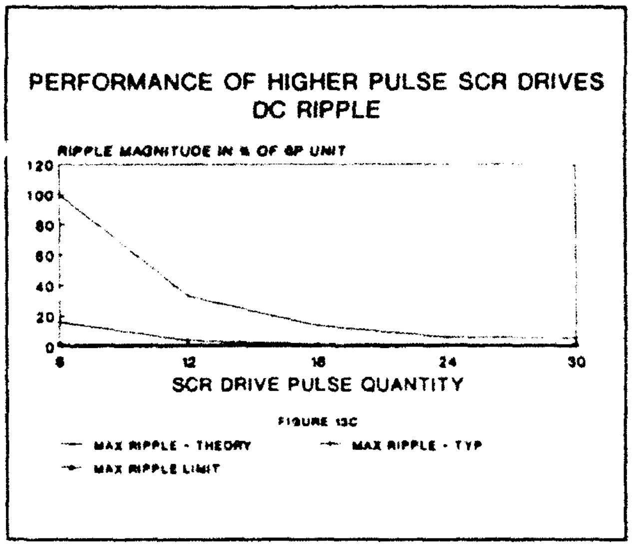


FIGURE 13C

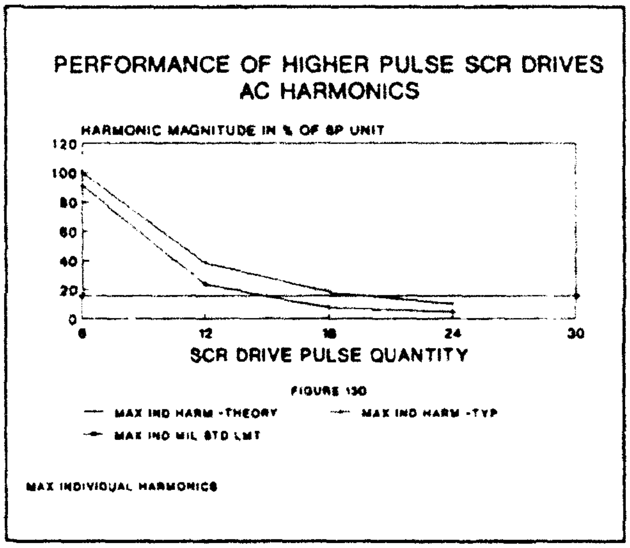


FIGURE 13D

Since there is little controllability of the notching effect internally within the SCR, increasing the inductance of the power source and distribution system remain the only option due to the characteristic of inductance to resist quick voltage changes. Methods of increasing a power source and distribution system reactance are adding a line DC ripple reactor or interphase transformer on the DC load side or high reactance transformer on the AC supply side. This is counter; however, to minimizing the effects of harmonic current since it is accentuated by the higher impedance (the lower the power source and distribution system impedance the lower the harmonic voltage drop presented). Reducing impedance in the power system becomes a compromise between reducing harmonics and limiting the short circuit or fault current available to within the switchgear capability since it is primarily dependent on the power source impedance. The fundamental current voltage drop for the largest motor load startup is also a factor here since voltage drop limits impose a controlling function on the maximum power source impedance limit as well that always counters the fault current concerns. In retrospect, if the harmonic current is minimized, the notching effect can be addressed more within the limitations of the fault current and large motor load voltage drop constraints because the higher impedance will not appreciably exacerbate the harmonic current provided.

Other reduction aspects involve filtering, which is most effective at the source of the harmonics or the loads requiring protection. Filters must address the lowest characteristic harmonic frequency present first to prevent a resonance condition at a harmonic frequency with a significant magnitude from developing below that filters tuned resonance. Since the largest magnitude harmonic frequencies are the lowest order fundamental harmonic frequencies, this is not a limitation, but a desired approach anyway. The normal practice is to separately fil-

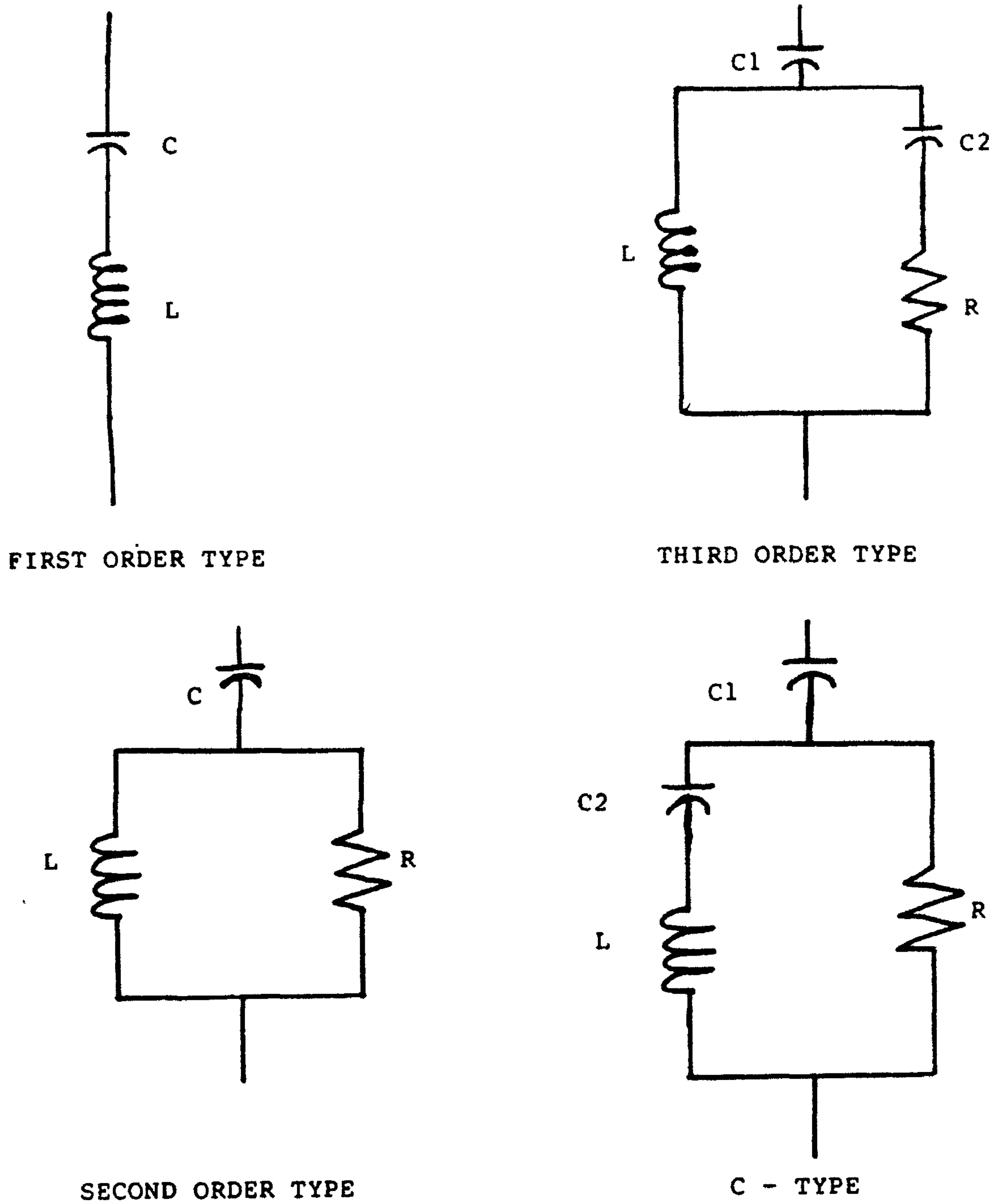
TABLE 6 [1,2,3]
HARMONIC CONTROL, REDUCTION, COUNTERMEASURES AND ISOLATION COMPARISON

ASPECT	PROS	CONS
Less Impedance	somewhat effective	limited by pwr sys fault current
Harmonic Injection +	very effective	expensive, complex unproven, large, heavy poor failure degradation
Isolation-		
Switchgear	100% effective some incremental failure capability	awkward operationally less efficient large, heavy ,expensive*
Transformer +	not effective	large, heavy, expensive* poor failure degradation
Motor/generator +	100% effective	large, heavy, expensive* poor failure degradation
Filtering	improves pwr factor reasonably effective	resonance , EMI & control stability concern tuning stability concern poor failure degradation locate near harm source
Sequential SCR devices within SCR unit	improves pwr factor somewhat effective	more complex larger, heavier much costlier
Higher pulse SCR units	improves pwr factor resonably effective	slightly complex somewhat heavier more costly increased space more balanced system parameters required

* at large power levels
\+ requires duplicate unit or several equally sized units

ter each of the two largest magnitude, but lowest order fundamental harmonic frequencies by tuned second order type filters (see Figure 14).[3] The remaining lower magnitude, but higher order fundamental harmonic frequencies are filtered together by a singular high pass second order type filter. This approach is still subject to creating a resonance condition at lower undesired frequency levels in the system, but not at a harmonic frequency of any substantial magnitude (all uncharacteristic frequencies are relatively small in magnitude despite the power system imbalance in impedance, source voltage and SCR group firing angles). Since filters are fixed, their tuning can be affected by power system impedance changes that reduce their effectiveness by essentially detuning them. Although a broader tuning spectrum function can be employed, this compromise reduces the degree of attenuation performance. These filters improve the power factor and are simple in design and not complex in operation unless controlled in sections for better tuning as system impedance varies. Space, weight and cost impacts of filters rise sharply with the amount of harmonic power to be dissipated and eventually make filters prohibitive to use for ratios of power that begin to approach half the level of the power source. If EMI is a concern, filters can cause additional impact to protect sensitive equipment. Generator control system instability also frequently arises and must be addressed via changing the feedback rate of the control system. Failures within filters can detune them, render them ineffective or lower their rating and complete unit failures may preclude the use of the higher order fundamental frequency filters due to resonance effects if it is the lower fundamental frequency filter that fails. Typically filtering is considered more of an easy fix to an existing harmonic source within an existing power system installation than a direct system design approach and is best suited for specific incremental harmonic improvements. A power rating degradation condition within a filter will overheat or fail it unless the SCR drive power service function is limited to the reduced level potential available.

Countermeasure techniques are fairly new and remain somewhat unproven and unaccepted, but are becoming increasingly employed in special applications. These techniques perform harmonic injection that can be quite effective, but the complexity, cost and weight and space impacts may be rather prohibitive for sizable power levels approaching half that of the power source, if the har-



FILTER CONCEPTS

FIGURE 14

TABLE 7 RECOMMENDED AC HARMONIC VALUES OF INDUSTRIAL NATIONS					
COUNTRY	EVEN MAX (%PU)*	ODD MAX (%PU)	MAX IND (%PU)	TOTAL MAX (%PU)	COMMENT
USA	NA	NA	NA	5.0	2.4KV-69KV
France	0.6	1.0	NA	1.6	ALL V
Sweden	NA	NA	NA	4.0	250V-430V
Australia	4.0	2.0	NA	5.0	BELOW 33KV
Finland	NA	NA	4.0	5.0	1KV
United Kingdom	2.0	4.0	NA	5.0	415V
Germany 5.0 less than 15th, 1.0 over 100th, ALL V - fundamental					
* %PU in reference to fundamental frequency voltage					

monic level is relatively high (over 5%). Failure performance is poor for countermeasures unless several banked units are used to develop the total power required or a complete backup unit is provided.

Isolation of loads from harmonics can be obtained by several means. The source of the harmonics will sometimes be isolated from the sensitive loads via switchgear configurations and flexibility in power sources (multiple transformers or generators). This approach is not always effective for industrial users that ultimately have just a singular source of power (transformer) from the utility. If the power source consists of generators, switchgear isolation is considered awkward operationally and inefficient due to additional use and light loading of multiple generators. Most frequently isolation is obtained at the sensitive load via motor/generator sets versus transformers because the transformers are not effective, especially at the lower order higher magnitude fundamental frequencies, and motor/generator sets are very effective. These motor/generator sets are often only used for relatively low power levels since the space, weight and cost impacts of these units becomes unattractive quickly as the power levels required increase toward half that of the power source. Unless several banked units are used to make up the whole power requirement or a complete backup unit is provided, there is no failure capability for a transformer or motor/generator isolation scheme. Switchgear on the otherhand fails more incrementally by steadily yielding less efficiency and operational flexibility.

Table 6 summarized all these points discussed in the section for analytical reference.

INDUSTRIAL RESPONSE TO HARMONICS

Historically industry has reacted to harmonics from SCR drives in one basic manner for two separate reasons. Usually the problems of high voltage and overheating effects are screened from the power system via trapping them in filters. Secondly these same filters provide an improvement in power factor (PF) that can be very productive for improving the efficiency of long transmission lines of utilities or reducing the industrial usage rate charge based on apparent power in voltamperes not real or ac-

PERFORMANCE IMPROVEMENT OF HIGHER PULSE SCR DRIVES

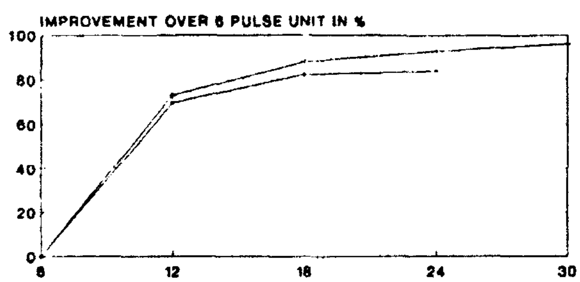


FIGURE 15

TABLE 8 NAVY SHIPBOARD HARMONIC REQUIREMENTS	
HARMONIC ORDER	MAX CURRENT VALUE (%PU)
AC LEVELS-	
Maximum Total	5.00*
Maximum Individual	3.00*
q pulse and multiples	0.16 +
All even and other below q pulse	0.04 +
DC LEVELS-	
Maximum Total DC Ripple	0.25 +
+ %PU in reference to fundamental frequency current magnitude * %PU in reference to fundamental frequency voltage magnitude	

TABLE 9 [4] RECOMMENDED IEEE STD 519 AC HARMONIC PARAMETERS			
SCR DRIVE SYSTEM APPLICATION	Z RATIO MAX	NOTCH AREA (V-MICRO SEC)	MAX TOTAL HARMONICS (%PU)*
General distribution system	5	22,800	5
Dedicated isolation system	2	36,500	10

* %PU in reference to fundamental frequency voltage

tual power in kilowatts ($P = PF \times V \times I$ for KW, but $S = V \times I$ for KVA is always greater if PF = 1 because $S = (P^2 + Q^2)^{1/2}$, where reactive power of $Q = I^2 \times X_{L,C}$ and $P = I^2 \times R$). If significant harmonics are present, the power equation actually becomes $S = (P^2 + Q^2 + D^2)^{1/2}$, where $D = I^2 \times Z$ and $Z = (X_{L,C}2 + R^2)^{1/2}$.

As a result of the power factor and harmonic equipment damage aspects, industry has evolved from using six pulse SCR drives to twelve pulse SCR drives as a standard practice. Industry normally employs a twelve pulse SCR drive above 4000 HP. Sometimes twenty-four pulse units are applied when either harmonic power quality or torque pulsations are a more important performance issue that is best solved by more of a systematic design approach versus the typical system characteristics modification by filtering. Note that the degree of harmonic content and power factor improvement for higher pulse SCR drives plateaus quickly after a twenty-four pulse SCR drive (see Figure 15). As previously stated, since industry has finally realized the difficulties harmonics can create, they have

AC HARMONICS VS LOAD VOLTAGE
WITH SEVERAL SC RATIOS

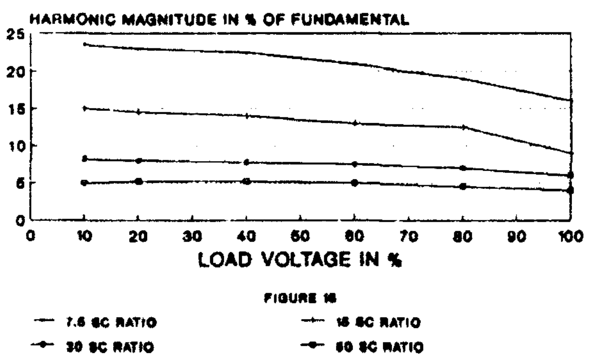


FIGURE 16

begun to address them technically and establish recommended standards of practice, which are displayed in Table 7 for the USA and some other major industrial countries. In reviewing these standards it is apparent via consensus that the maximum total and maximum individual harmonic levels should be 5% and 3%, respectively (which is consistent with shipboard practice, see Table 8). Additional specific harmonic design parameters of impedance ratio and notching level are also recommended by IEEE STD 519 (Table 9) since these parameters significantly affect harmonic performance. It should be kept in mind that harmonics are usually low in the utility voltage levels, but become high in the industrial voltage levels if for no other reason than just the higher current level involved at lower voltage use as well as the closer proximity of the local power source to the harmonic source and lower short circuit (SC) ratio (system fault current capability in MVA or KVA/harmonic source's actual power in MW or KW) (see Figures

AC HARMONICS VS SC RATIO
FOR 24 & 36 PULSE RECTIFIERS

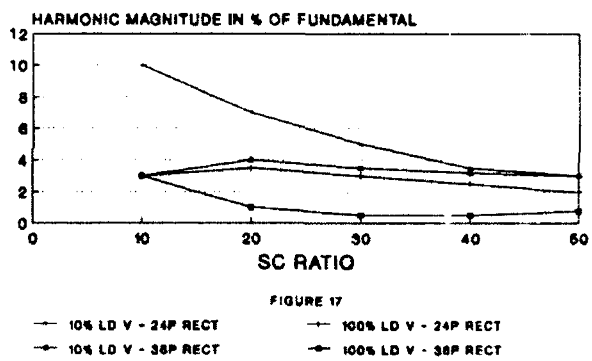


FIGURE 17

AC HARMONICS VS SC RATIO
FOR 6 AND 12 PULSE RECTIFIERS

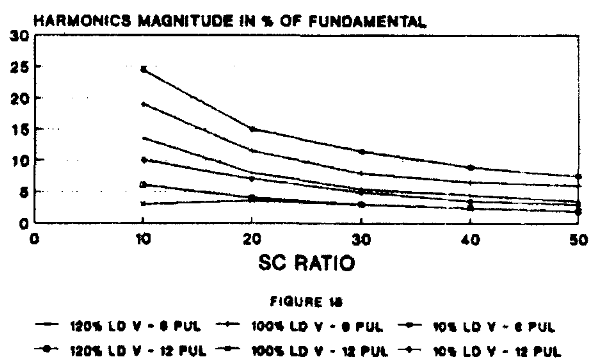


FIGURE 18

16 and 17)[5]. In fact, the IEEE STD 519 guidelines (see Figure 18)[4] for harmonics provide a gauge of the expected harmonic level for a given pulse quantity in a SCR drive and its associated SC ratio that further illustrates this aspect. Reference 5 recommends a SC ratio value greater than 20 for SCR drives with less than 18 pulses if no filter provided. If consistent harmonic performance is desired over a wide operating range of DC voltage versus a constant level, then a SC ratio of over 20 should be imposed for SCR drives with less than 24 pulses according to Reference 5.

SHIPBOARD RESPONSE TO HARMONICS

The original DC motor drive ships were provided power from DC generators in either series or parallel configurations (see Figure 19). Although such systems provided convenient generator field control of the propulsion drive motor, the high speed brush problems, inefficiency of DC generation and limitations of DC switchgear have provided firm reasons to embrace the SCR technology.

Shipboard power quality has always been defined by MIL-STD-1399 Type I and DC ripple has recently become established at specific levels in the GEN SPEC For T-Ships (see Table 8). However, power quality has rarely been achieved in actuality with the most T-ships, even after filtering. This is partially because of the inherent time lag of 5 to 10 years between industry practice and commercial marine and navy technology use and partially due to the minimal initial cost design policy for these ships. Until just recently the inexpensive minimum six pulse SCR drive design has been employed universally with filtering as required to tame some of the adverse AC or DC harmonic conditions created and reduce the major problems encountered. Only in the past several T-ship designs has real progress been made toward obtaining MIL-STD-1399 quality power throughout the electric plant. MIL-STD-1399 quality power has now been invoked more adamantly than ever before with T-AGS 60. However, there are several other key harmonic parameters not addressed by MIL-STD-1399 concerning voltage notching and impedance and short circuit ratios.

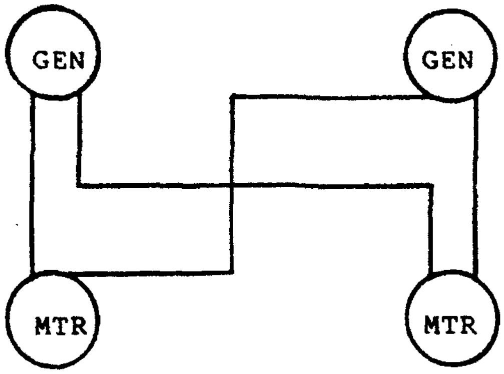
The primary philosophy of the shipboard approach is usually to isolate the harmonic source or sensitive loads versus addressing the entire system problem. This has the superficial appearance of being less impact in cost, complexity, weight and space. Such an arrangement typically functions acceptably if the harmonic source or sensitive loads are relatively small in comparison to the power source or the PC Ratio is relatively high (propulsion power to clean power). Such a configuration (see Figure 20) allows an uncontrolled "dirty" bus of high harmonics for most ship service loads and a very controlled "clean" bus of very little harmonics for sensitive loads. AC or DC filters can be added to reduce the dirty bus impact and often are after sufficient operational problems demand it. Filters can be placed at the main bus or at the SCR drive, but are generally placed at the SCR drive for more effectiveness (see Figure 20, examples are T-AGOS 1,13 and 19). Additional reactors are added between the SCR drive and the DC motor to further reduce DC ripple effects. Some ships (examples are T-ARC 7, GLOMAR PACIFIC and T-AGS 195) have taken a quasi system filtering approach, since their filters are at the main bus and not at the AC side of the SCR drives creating the harmonics.

Both of these design approaches are the same basic configuration and seek to reduce the harmonics to a reasonable level that would minimize the harmonic problems, but still required isolation via motor/generator sets for the sensitive loads. This is in effect working the harmonic issue rather equally from both sides to gain an acceptable solution via compromise instead of a simply using a more direct approach. The harmonic levels experienced and expected on recent and future integrated diesel electric AC generation/DC propulsion plants are reviewed in Tables 10 and 11, respectively. Note that the mission condition SC ratios are all rather high (30 or much greater), but most of the full speed condition SC ratios are well below 20. The PC ratio can exceed 50, but generally ships with propulsion requirements comparable to the ship service load demand have PC ratios of less than 10. More typical ship propulsion to ship service PC ratios appear to range from 20 to 30. Harmonic perfor-

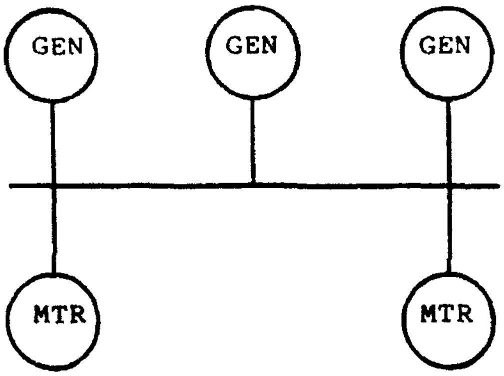
TABLE 10
ACTUAL AC HARMONIC LEVELS IN SHIPS

SHIP TYPE	MAX IND (%PU)**	TOT MAX (%PU)	GEN X	SC RATIO F	SC RATIO C	SC RATIO M	PC RATIO	PULSE LEVEL
GLOMAR PACIFIC	7+-10*	9+-18*	NA	NA	NA	NA	60	6
T-ARC 6	NA	9-15	.18	NA	NA	NA	NA	6
T-ARC 7	13+-17*	24+-30*	.25	17	24	74	30	6

FP full power level; MP mission power level; () without filtering; * propulsion bus
CP cruise power level; SC short circuit; + ship service bus; PC propulsion/clean power
** %PU in reference to fundamental frequency voltage



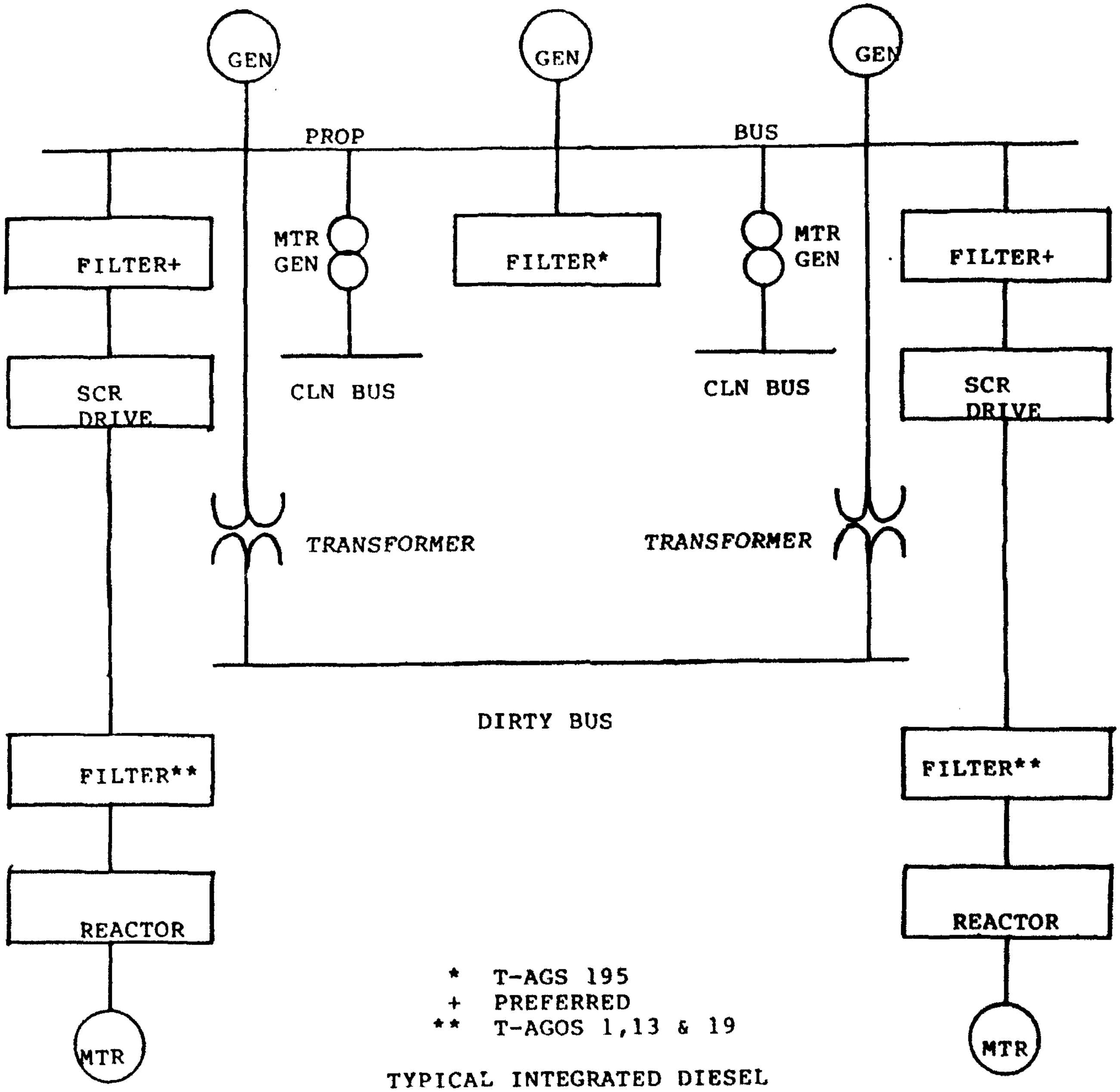
SERIES TYPE
(WIRING CONNECTIONS)



PARALLEL TYPE
(BUS CONNECTIONS)

SHIPBOARD DC GENERATION/DC PROPULSION CONCEPTS

FIGURE 19



* T-AGS 195
\+ PREFERRED
** T-AGOS 1,13 & 19

TYPICAL INTEGRATED DIESEL
ELECTRIC AC GENERATION/DC PPROPULSION
PLANT CONCEPT

FIGURE 20

TABLE 11
ESTIMATED AC HARMONIC LEVELS IN SHIPS

SHIP TYPE	MAX IND (%PU) **	TOT MAX (PU%)	GEN X	SC RATIO			PC RATIO	PULSE LEVEL
				FP	CP	MP		
T-AGOS 1,13	4 (7)	8 (15)	.15	18	33	200	7	6
T-AGOS 19	4 (7)	8 (15)	.15	22	33	92	7	6
T-AGS 195	5 (11)	9 (24)	.20	26	39	30	8	12
T-AGS 45 +	5	10	.16	18	20	72	19	12
AGOR 23*	2 (6)	4 (13)	.18	19	19	48	30	12
T-AGS 60 +	3	5	.18	7	30	56	64	24
T-AGOS 23	5	10	.20	16	23	204	19	12
T-AGS(O) SWATH A	NA	5-7	.21	16	23	108	19	12
T-AGS(O) (ICE CAP)	5	10	.20	16	23	150	19	12

* if true integrated electric AC generation/DC propulsion plant with twelve pulse SCR drive
+ no isolation with motor/generator set required () without filtering
FP full power level CP cruise power level MP mission power level SC short circuit PC propulsion/clean power
** %PU in reference to fundamental frequency voltage

mance ranges from a high of 30% and 17% for maximum total and individual frequency values, respectively, to right at the MIL-STD-1399 power quality requirements.

Unfortunately, shipboard information on impedance ratios and voltage notch effects are not readily available for compared with IEEE Standard No. 519. Typical harmonic performance versus propulsion duty for a ship (T-AGS 195) with and without a filter and for an actual ship (T-ARC 7) under several operating scenarios are shown in Figures 21[8] and 22[9], respectively. It is readily apparent from Figure 21 how the power source impedance plays a major role in the degree of harmonics experienced (low speed single generator/motor (one SCR drive) condition has worse maximum harmonics than a full speed four generator/two motor (two SCR drives) condition in the electric plant and the overall worst case is at cruise condition with three generators). Figure 22 illustrates the fact that although harmonics increase at low power levels, their effect is anticipated to be lessened in a total sense by their overall lower power level (i.e., a larger percentage of a small number is still a relatively small value).

T-AGS 195 AC HARMONIC DISTORTION
VS PROPULSION SPEED (ESTIMATED)

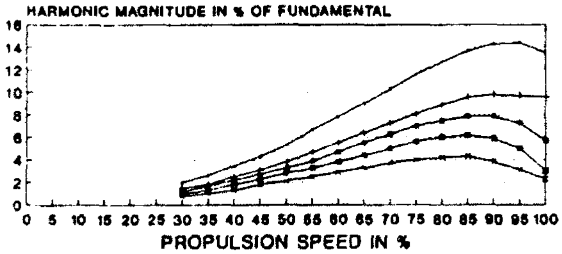


FIGURE 21

6 PULSE UNIT 12 PULSE UNIT 12P UNIT -11/13 FLTR
12P -11 TO 25 FLTR 12P - ALL FILTERING

USNS HAYES

T-ARC 7 TOTAL AC HARMONIC DISTORTION
VS PROPULSION SPEED (MEASURED)

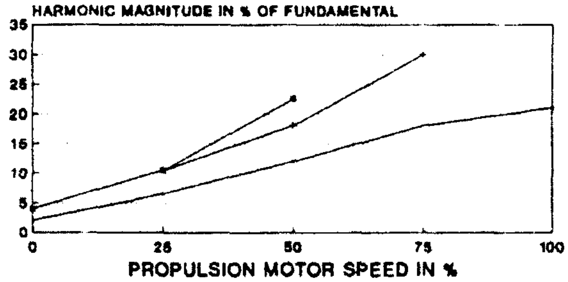


FIGURE 22

2 MTR - 4 GEN 2 MTR - 2 GEN 1 MTR - 1 GEN

USNS ZEUS

7

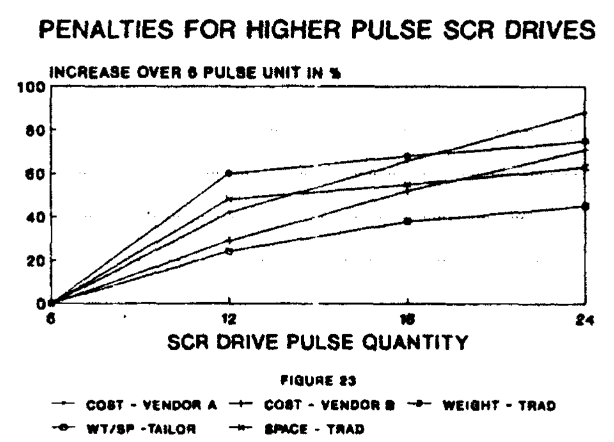


FIGURE 23

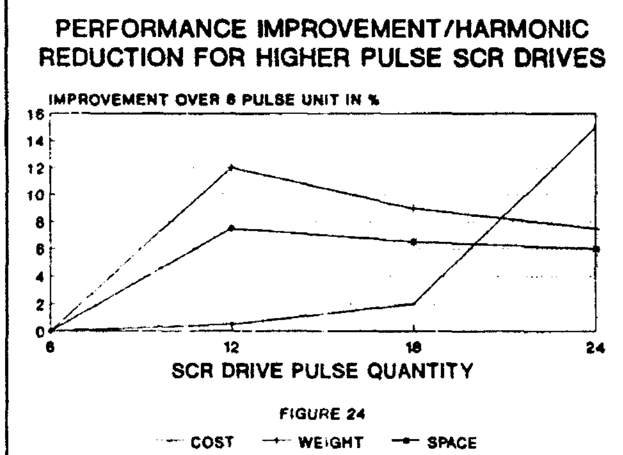


FIGURE 24

DISCUSSION

SHIPBOARD CONFIGURATION EVOLUTION

Initially each SCR drive was dedicated to each shaft, but this caused excessive harmonics from one not two SCR drives operating and lower power level use than necessary for the SCR drives. Now during half power or less for ship propulsion power demand only a single SCR drive is employed and the two motors are series connected to more easily match the two propeller speeds and reduce the harmonics generated (one SCR drive being at full power creates less harmonics than two SCR drives at half power). The T-AGS 195 and T-AGOS 23 ship designs have evolved into 12 pulse SCR drives and all other T-ship designs have been with 6 pulse SCR drives. The recently awarded T-AGS 60 goes a step further by taking advantage of the two shafts configuration aspect to transpose the final phase shift of two 12 pulse SCR drives into a 24 pulse SCR drive for two motors versus producing two 24 pulse SCR drives (one for each separate shaft).

As previously indicated, the unacceptability of tolerating the resultant high harmonic levels of the dirty bus, employing a filter or allowing high DC motor vibration has now led to the more common use of twelve pulse SCR drives. This has dramatically lessened the harmonics, but not generally to the level acceptable for sensitive loads or MIL-STD-1399 power quality without additional filtering. Predominately the twelve pulse SCR drive has been chosen for the DC ripple reduction or DC motor noise concern rather than power quality. Although this is a step in the right direction for adequate power quality, additional filtering is not provided for meeting the MIL-STD-1399 power quality in the electric plant as should occur and is always specified. Although the typical load isolation approach is reasonable for relatively large PC Ratios if the bulk of the ship service load can accept a dirty bus, it is not a recommended practice. Such dirty bus harmonic levels should at least be kept below 10% for maximum total harmonic distortion if major problems are to be avoided.

The question that surfaces is "Is a more systematic design approach in order and how is it best resolved?". The potential solutions for addressing MIL-STD-1399 power quality are via continued higher pulse SCR drives or more filtering or a combination of both. Again, filtering is not generally considered a reliable continuous means of obtaining a large harmonic reduction due to its potential resonance, EMI, and control system destabilization and overheating potential from failure degradation. Filter overheating concerns have imposed switchgear by-pass capability, forced draft cooling fans and temperature indication and alarms because of the critical propulsion function is jeopardized when the filter is connected between the SCR drive and the DC motor. Filtering is really best suited for modifying an unsatisfactory existing SCR drive design performance, particularly when integral within the base SCR package rather than an additional separate item. Because the higher pulse SCR drives are tailor designed versus the typical doubling up of the six pulse SCR groups for a twelve pulse SCR drive, the increased filtering coupled with the base twelve pulse SCR drives to achieve a given low harmonic performance are likely to be larger and heavier than a comparable performance from a twenty-four pulse SCR drive. In addition, the multiple component aspect of several transformers and SCR groups provide the desired shipboard redundancy. However, since filtering is much less expensive than SCR drives, filters could be used in a backup augmentive function to correct the results of a six pulse SCR group failure in a higher pulse SCR drive via non-fed through connection on the main ship service bus or on the power

feeder to the SCR drive. Filters would also be quite effective at reducing any uncharacteristic harmonics since the transformers do not appreciably effect such positive sequence current.

HIGHER PULSE SCR DRIVES STUDY

Now the question has been narrowed to basically "How many pulse SCR drive is required for an optimal performance?". Figure 13 illustrates the aspects of higher SCR pulse drives against the actual and theoretical harmonics, worst case power factor and DC ripple to the MIL-STD-1399 power quality. Since the DC ripple level requirement is so very low at .25% for maximum individual ripple frequency, it must be attained by DC line reactors or much higher SCR pulse groups (see Figure 13). The typical range of DC motor inductance is 200 uh to 450 uh, which does not in its self offer much ripple smoothing. In contrast, the higher SCR pulse drives do achieve MIL-STD-1399 power quality for both maximum individual frequency and maximum total distortion level at about eighteen pulses (Figure 13). The penalties for higher SCR pulse drives are depicted in Figure 23 in terms of cost, space and weight impacts from several manufacturers and approaches of both older traditional and newer more advanced tailored designs. The benefits of better packaging for SCR drives are readily apparent.

Further examination of these penalties against the harmonic performance separately (see Figure 15) and together (see Figure 24) reveal very defining aspects for higher pulse SCR drives. The most notable fact is the harmonic performance trends to flatten out considerably after eighteen pulses. A review of the penalties per their harmonic performance improvement indicates a substantial increase in cost beyond an eighteen pulse SCR drive, but a rather level space and weight impact beyond twelve pulses after the initial rise to twelve pulses from six pulses. Interestingly, too, the weight impact actually decreases beyond twelve pulses after initially cresting at six pulses. It appears that the major penalty actually occurs between 6 and 12 pulses, except for continued cost increase and this may not necessarily remain so since it is highly dependent on the power level required and innovative engineering application, such as with the T-AGS 60.

The conclusion drawn from the brief study of these graphs is to employ eighteen pulse or greater SCR drives for obtaining shipboard MIL-STD-1399 power quality. However, since industry appears to abhor eighteen pulse SCR drives in general, probably twenty-four pulse SCR drives would be provided. This would be even better in harmonic performance and most other characteristics of interest, but could be well beyond the point of diminishing returns in terms of cost.

CONCLUSIONS/ RECOMMENDATIONS

In accordance with this brief higher pulse SCR drive study, other commercial practice and IEEE STD 519 recommended guidelines, the following design parameters are suggested for shipboard SCR drive systems for DC motor propulsion in integrated diesel electric plants: (although not much shipboard information is available for comparison on past/present Z ratios or notch areas)

- provide eighteen pulse SCR drive
- all AC filtering located on the AC side at the SCR drive, preferably integral within the unit
- no more than 3% and 5% maximum individual frequency and total harmonic distortion, respectively
- notch area no greater than 22,800 volt-micro seconds
- SC ration greater than 20
- Z ratio greater than 5

If an integrated diesel electric plant is provided with an isolated ship service bus section, then the following design parameters are suggested:

- provide a twelve pulse SCR drive
- all AC filtering located on the AC side at the SCR drive, preferably integral within the unit
- no more than 5% and 10% maximum individual frequency and total harmonic distortion, respectively
- notch area no greater than 36,500 volt-micro seconds
- SC ratio greater than 15
- Z ratio greater than 2

If a separate duty propulsion bus is provided, then the parameters for that system may be as required for that specific system to operate acceptably. DC ripple requirements should also be tailored to that of a specific ship design requirement since it has little bearing on the AC harmonics. Ideally, all bow thrusters with SCR drives would preferably be treated the same as propulsion motors. It is particularly recommended that if the bow thruster is relatively large with respect to the generation plant (low SC ratio effectively) or if several bow thrusters

are employed, the isolated ship service bus requirements for an integrated diesel electric plant should at least be applied. Six pulse SCR drives should not be used for any relatively large loads aboard ship.

To further confirm the best approach of establishing MIL-STD-1399 power quality in integrated diesel electric AC generation/DC propulsion plants, additional detailed study should be conducted and actual shipboard data should be obtained on SCR drive installations with 12 pulses or higher since sufficient data already exists on shipboard 6 pulse SCR drives (T-ARC 7).

REFERENCES

[1] "Harmonics For Electric Distribution Feeders", Oak Ridge National Laboratories, ORNL/SUB-81-95011/4 (DE 88007849)

[2] "Standard Handbook for Electrical Engineers", 10TH Edition, D.G. Fink and J.M. Carroll editors, McGraw-Hill Book Company, 1969

[3] "Power System Harmonics", J Arrillaga, D.A. Bradley and P.S. Bodger, 1985, J. Wiley & Sons Ltd.

[4] IEEE Standard No 519 - 1981, "Guide for Harmonic Control and Reactance Compensation of Static Converters"

[5] "Reactive Compensation and Harmonic Suppression for Industrial Power Systems Using Thyristor Converters", D.E. Steeper and R.P. Straford, IEEE Transactions on Industrial Applications VOL. IA-12 NO. 3, May/June 1976, p 232-254

[6] "Line Harmonic of Converters with DC Motors", A. David Graham and Emil T. Schonholzer, IEEE Transactions on Industrial Applications VOL. IA-19 NO. 19, Jan/Feb 1983, p84-93

[7] "Electric Waveform Distortion: Their Hidden Costs and Containment", John R. Linders, IEEE Transactions on Industrial Applications Vol. IA-15 NO. 15, Sep/Oct 1979, p. 458-471

[8] USNS HAYES (T-AGS 195) CDRL No. A042-5, "Harmonic Analysis-AC Line Filters", 28 Aug 1989

[9] USNS ZEUS (T-ARC 7) DTNSRDC TM-27-84-20, "T-ARC 7 (USNS ZEUS) Electrical System Characterization", 31 May 1984

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Combat Systems Design Office
(SEA 06D441)
Naval Sea Systems Command

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List of Figures

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Nomenclature

AZ	Azimuth
CNO	Chief of Naval Operations
EL	Elevation
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMENG	Electromagnetic Engineering
EMGEO	Electromagnetic Geometry Modeler
EMI	Electromagnetic Interference
EPY	Expanded Planning Yard
FCB	Future Class Baseline
FMP	Fleet Modernization Program
GADS	General Arrangement Design System
HM&E	Hull, Machinery and Electrical
ICB	Initial Class Baseline
IGES	Initial Graphics Exchange Standard
OPNAV	Chief of Naval Operation's Staff
PCB	Projected Class Baseline
PHM	Patrol Hydrofoil Missile Boat
RAM	RADAR Absorbing Material
RF	Radio Frequency
SEMCIP	Shipboard Electromagnetic Compatibility Improvement Program
SHIPALT	Ship Alteration
SLM	Ship Logistics Manager (Program managers for ship maintenance rather than acquisition)
SMITS	Shipboard Management Information Tracking System
STACM	Ship Topside Arrangement Configuration Management Program
STAN	Shipboard Technical Assistance Network
TAS	Target Acquisition System
TDM	Topside Design Model
TEA	Topside Elements Attribute
Topside	Shipboard area continuously exposed to the weather, such as main deck and above, sponson decks and the superstructure
TYCOM	Type Commander
WCAP	Waterfront Corrective Action Program
WIP	Warfighting Improvement Plans

Introduction

Electromagnetic Interference (EMI) is a problem our sailors deal with daily. Several programs have been initiated to improve the Electromagnetic Compatibility or EMC status of our naval ships. The topside design and integration process has been structured to provide guidance to the task leaders responsible for that portion of the ship design process. Many Fleet EMC improvements have been made and computer tools have been developed to assist with the minimization of EMI. A program called EMENG is being pursued that provides a planned approach for computer tool development. But there are still many areas where improvements can be made. Additional computer tools are needed. Better EMI measurement devices are required. Electronic equipment development must be more closely coordinated with the environment in which it will operate.

FLOW CHART FOR TOPSIDE DESIGN

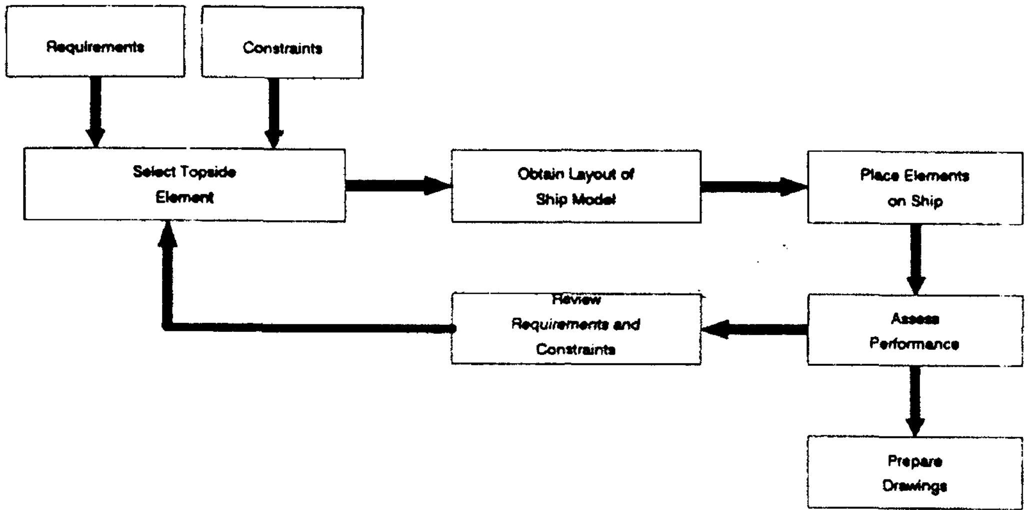

Figure 1

These issues are addressed in this paper, and challenges are proposed to the engineers who will have to deal with EMI in new design and Fleet support.

Current Topside Design Process

The number one goal in a ship designer's approach is to maximize overall ship performance in meeting mission requirements, within the operational and economic constraints imposed. While performing the topside design process, this must always be kept in mind. However, in describing the topside design process in this paper, we will concentrate on an objective specific to the topic; i.e. to provide optimum coverage and performance of guns, missile launchers, weapons directors, radars and communication systems and to minimize the degrading effects of EMI to fulfill the ship's many missions.

In order to accomplish this objective, an orderly set of steps has evolved. This section will briefly describe those steps. The steps consist of the following:

A. Review mission requirements and design constraints.

B. Select topside elements from shopping list.

C. Layout ship model.

D. Place topside elements on ship.

E. Assess performance.

F. Prepare drawings.

Figure (1) depicts these steps in a flow chart format. Briefly, it shows that given a set of requirements and constraints, a suite of topside elements is selected that can meet mission objectives. In most cases, the Chief of Naval Operations (OPNAV) specifies the major portions of the combat system in the Top Level Requirements (TLR) document. Next, a three dimensional description of the ship is obtained in the form of drawings or a computer model. Then the topside elements are initially placed on the ship using the designer's experience, knowledge and lessons learned. Various assessments are performed, and if they are satisfactory, drawings are prepared to show the locations of the elements. However, if the assessments prove unsatisfactory (which is usually the case) the process is started again and completed only when an arrangement of least compromises is obtained.

Each of the five steps outlined above is discussed in further detail in reference [1].

EMI Problems in the Fleet Today

The quantity of electronics aboard ships is growing at a fantastic rate. A typical aircraft carrier has more than

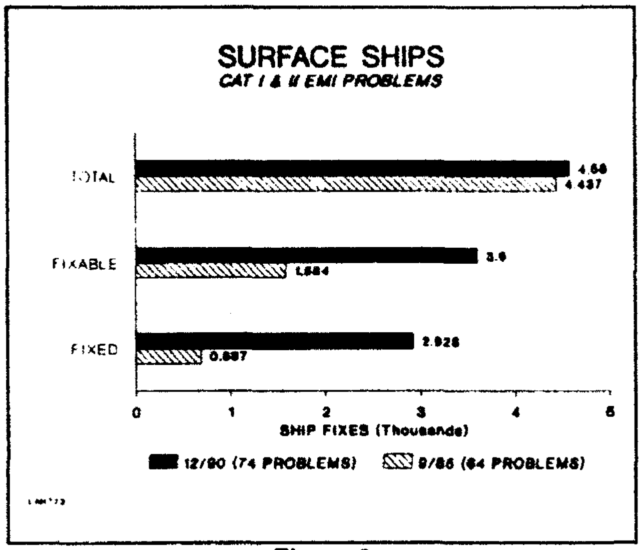

Figure 2

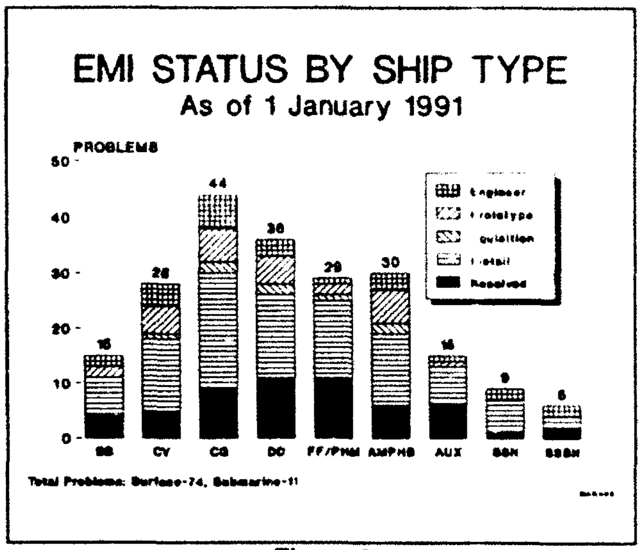

Figure 3

125 antennas topside, and a tremendous complement of electrical and electronic systems. Reference [2] describes many causes of EMI and shipboard EMI problems in the Fleet today. Because of the proliferation of both approved and unapproved electronic systems being installed on our ships today, there exists many opportunities for problems.

Figure (2) is a summary of the number of EMI problems in the Fleet today. Figure (3) provides the EMI status of these problems by ship type. These summaries were obtained from the Shipboard Management Information Tracking System (SMITS). SMITS not only provides the status of EMI problems in the Fleet, but also provides valuable lessons learned to the design community, shipyards and industrial activities.

The Shipboard Technical Assistance Network (STAN) is an unclassified version of SMITS. It is available for use worldwide, 24 hours a day, just by dialing an 800 number from a computer terminal. But you must have a password. With proper justification, a password will be assigned by NAVSEA 06D44.

EMI problems stored in SMITS and STAN, are categorized according to their impact upon the operational performance degradation of the victim equipment or system. Three levels of mission degradation are used to define the numerical categories:

Category "1" (CAT 1) = EMI exists when a primary/secondary mission essential system/equipment is receiving interference and is unable to support its mission. Highest priority engineering efforts are devoted toward resolution of CAT 1 problems.

Category "2" (CAT 2) = EMI exists when a primary/secondary equipment is receiving interference, but is still able to support its mission in a measurably degraded mode. High priority engineering efforts are dedicated toward resolving CAT 2 problems.

Category "3" (CAT 3) = EMI exists when a primary/secondary equipment is receiving interference, but is still able to support its mission with little or no degradation. In addition, EMI affecting backup or redundant systems and systems less critical to Fleet operations (ship's entertainment, amateur radio, etc.) or EMI resulting from improper maintenance practices is considered CAT 3, regardless of the engineering impact on system performance. Scarce engineering assets are not to be assigned to CAT 3 EMI problem resolution. Depending on tasking, CAT 3 problems may be addressed through the Shipboard EMC Improvement Program (SEMCIP) Waterfront Corrective Action Program (WCAP), when appropriate.

EMI brief sheets can be obtained from the STAN computer database. Definitions describing each of the brief sheet elements are detailed in the STAN Users Manual, which can be obtained from SEA 06D44 and will not be detailed here.

Appendix A in reference [1] includes several sample EMI Problem Brief Sheets from SMITS that show that EMI is not solely a topside or combat system problem but affects systems both above and below deck. The once immune Hull, Machinery and Electrical (HM&E) systems are now as susceptible as combat systems and potentially more dangerous. HM&E EMI can put a ship dead in the water or render any weapons system or combat system useless. We have often come close to this situation. EMI has caused the PHM to crash off its foils, has set off fire

alarms, rendered new firefighting equipment useless, caused missiles to fire at the wrong azimuth and has caused flight safety problems for shipboard aircraft. Additional EMI problems are discussed in reference [3].

Electromagnetic Energy Control

The complexity of a Navy shipboard environment hinders the engineering community in identifying a reported equipment problem as an EMI problem. The multitude of electrical and electronic equipment all radiate and absorb both electric and magnetic fields at varying levels and generate and respond at their cable terminals to electromagnetic (EM) energy as radio frequency (RF) currents. The many miles of shipboard cables also radiate and conduct EM energy into and out of compartments, passageways and literally everywhere in, on and around the ship. If the EM engineer is to solve EMI problems in this complex EM environment, then system engineering approaches such as optimization applications and modularizing problem solving processes must be used. The simple definition of the engineering problem statements must be used by the EM engineer to better his understanding of the EM phenomena causing the interference and, therefore, control the EM parameters to solve the interference problem.

As defined by Webster's Dictionary, the word "control" means: To exercise restraining or directing influence over a mechanism used to regulate or guide the operation of a machine, apparatus or system, to reduce the incidence or severity especially to innocuous levels.

To "control" the EM energy that is created, propagated and observed within the topside environment of a Naval ship, an EM engineer has to determine design dependencies associated with each major component of the EM analysis problem. Segmenting the problem into three distinct components allows the systems engineer to model individual parameters within a locally definable problem environment. Each local problem environment can then be analyzed utilizing techniques that are optimized for that problem environment. The three general local problem environments for EM engineering problem solving aboard a naval ship are:

- SOURCE MODELING
- PROPAGATION MODELING
- OBSERVER MODELING

Individual local problem environments are combined together to solve a particular EM engineering problem. To maintain independence between the local problem environments, an interface matrix is established. This interface matrix contains the variables (and their interdependencies either in mathematical or numeric form) required to define the EM environment in its entirety at the point of the interface with another local environment.

The ability to "control" the EM environment has now been reduced to a simpler more manageable level that is more amenable with the type of system interference problems faced by the naval EM engineer. If a particular EMC problem is being analyzed, it is essential that the EM energy parameter capable of crossing over an interface threshold between two local problem environments be completely described and relatable to the performance measure for interference determination at the observer model. This energy parameter can then be analyzed at each local problem environment to determine if a particular local problem environment has an overriding impact that determines the value of the parameter under consideration. In many cases a particular local problem environment can be manipulated to change the value of the parameter under investigation. Manipulations within a local problem environment, particularly by changing the spatial relationships of source equipment and observer (most probably equipment) locations, can drastically change the values of the parameter within the interface matrix thus affecting the final problem solution.

The power of segmenting the EM problem should now be evident. The EM engineer has the option of looking for potential solutions within each individual local problem environment. A particular local environment may be much easier to manipulate (due to dollars, schedule, direct engineering control, production issues). A particular local environment may be under the direct control of the EM engineer thus allowing a design change to be realized, a change that directly and quantifiably "controls" the EMC of the overall ship design.

MODELING DEVELOPMENTS FOR TOPSIDE DESIGN

EM energy propagation is a well understood phenomenon when the local area of interest is quite far away from the source of the energy. The definition, or scientifically accepted convention, of this boundary known as the "far field" can be expressed as follows:

$$FF = \frac{2D^2}{\lambda}$$

where FF = the beginning boundary of the far field (meters)
D = the largest linear dimension of the source (meters)
λ = the wavelength of the energy under consideration (meters)

TABLE 1	
Antenna	Far Field Distance In Feet
AN/SPS-55	815
AN/SPS-48	1659
AN/SPQ-9	930
AN/SPG-60	1055
AN/SPG-51 Track	686
AN/SPG-51 Illuminate	1177

TABLE 2	
SHIP CLASS	SHIP LENGTH IN FEET
AD 41	643
BB 61	887
CVN 68	1092
CG 47	563
DD963	563
FFG 7	445
LHD 1	845

Within this far field region the losses associated with EM energy propagation in free space (uncluttered with other metallic or electrically conductive objects) are easy to predict and verify. This far field region is the region of interest to the microwave antenna designer for it is in this region that energy comes in contact with targets of interest (the very items the antenna is designed to "see"). Targets are immersed in this energy and reflect some portion of it (although very minor) back in the direction of the source antenna. In effect, this target is now acting like a small source of EM energy itself as seen by an outside observer. Whatever shape, material and arbitrary angle the target holds with respect to an outside observer will define antenna-like parameters of energy propagation (e.g. phase, polarization, angle of propagation and gain). From an analytical point of view the target has become another source of EM energy. In this way the antenna designer can establish the target as a sub-source of relatively small intensity and then continue the assessment treating it analytically as any other source with far field characteristics.

The above equation for the definition of the boundary for the far field still holds for the sub-source. The energy now on its return path from the sub-source to the original source travels into the far field before reaching the original antenna, now responding as a receive antenna vice source antenna. The receiving antenna is now available to respond to its original energy, reflected off a target and changed in accordance with the target's local EM response as a sub-source. The receiving antenna is in the far field region of the sub-source. Since the EM energy at the receive antenna is in the far field, EM parameters are predictable and verifiable and become one of the dependencies of the definition of performance thresholds for the radar system itself.

This oversimplified explanation for EM energy propagation from a microwave antenna identifies a primary area of design consideration a radar system engineer uses in assessing propagation effects for the determination of radar performance goals. The EMI problem associated with two unique antenna systems operating simultaneously in the topside of a Navy ship normally involves a geometrical arrangement wherein both antennas are not in the far field of each other. Table 1 shows some of the far field distances of some more common Navy microwave antennas.

The problem of arranging these types of antennas in the confined geometric environment of a Navy ship topside is clearly identified when the ship lengths of table 2 are compared with the far field distances of table 1. Total ship topside length is also not all usable space since much topside area is dedicated to the primary mission of the ship (e.g. flight deck of a carrier or amphibious assault ship, crane service for an auxiliary, 16 inch guns for a battleship). It is in many cases physically impossible for the topside designer to place antennas in the far fields of other antennas and, therefore, take advantage of the predictability of EM energy propagation that the antenna designer himself relies upon. The EM engineer, in support of achieving EMC among topside antenna systems, has been struggling with the problem of predicting and verifying the effects of differing near field conditions on the radar system designer's far field performance requirements.

PROPAGATION MODELING TECHNIQUES

Presently three techniques, empirical, spectral and ray techniques are utilized by the EM engineer to assess near field EM energy effects.

EMPIRICAL TECHNIQUES

Empirical techniques are used to "ballpark" estimates on the amount of energy coupled into one antenna as a result of emissions from another nearby antenna. Empirical techniques have great appeal due to speed of calculations and provide bounding of problems when the complete set of attributes of a problem are not yet defined. However, empirical techniques generally combine source, propagation, and observer elements into one model and, therefore, do not provide much insight into the cause of the problem (or the specific dependencies that drove a particular result). This hinders the EM engineer in identifying and prioritizing potential problem solutions.

SPECTRAL TECHNIQUES

Spectral techniques (which are relatively new to the application of EM field prediction on the scale of a Navy surface ship) are based on the fact that an arbitrary energy wavefront (that orientation of EM energy commonly found in near field energy conditions) can be decomposed and represented as a sum of plane waves (that orientation of EM energy found in the far field energy conditions) propagating in a spectrum of different directions. These component plane waves can be individually examined in relation to an intervening structure or scatterer. A new excited spectrum of plane waves can be determined that represents the scattered or reflected energy field from this one component of the incident field. The incident and scattered plane waves are then mathematically combined to form the total near field. Spectral techniques are well suited to parallel processing calculation techniques and may prove very useful in the future. A detailed explanation of spectral techniques can be found in Reference [4]. Naval ship design applications of spectral techniques will be left to future publications.

RAY TECHNIQUES

Ray techniques, originally applied to support the radar cross section reduction studies in the aircraft industry, are the third technique currently used and will be the subject of further discussion within this paper. Ray techniques are broken down into two subsets, ray tracing and ray casting techniques. Both techniques utilize the concepts of Geometric Optics (the optical or direct path characteristics of EM energy) and the Uniform Theory of Diffraction to calculate the strength of rays diffracted by surface discontinuities (this being the optical shadow regions in and around a complex geometry). The application of either ray tracing or ray casting is based on the fact that, at frequencies of application (normally the microwave frequency regime), the geometry elements of a ship are generally large compared to the wavelength of the EM energy being studied. Therefore, simulating EM energy propagation with rays can be accomplished.

Major shipboard structures such as masts, yardarms, platforms, ladders, decks, and bulkheads are defined during the ship design process. Requirements of location, orientation, material, shape and equipment location are all specified in the drawings and ship specification. Ray techniques can and are being used to support ship design in analyzing these structures. These are the items that define the major near field effects on microwave antennas.

Very simply, the ray technique models are executed as follows:

1. A three-dimensional geometric definition of the ship under investigation is obtained (sometimes created) to a resolution consistent with the frequency of the analysis. The geometric element size or the level of detail is dependent on the wavelength (and therefore the frequency) of the analysis. As frequency gets higher and the wavelength gets shorter, more detail is required to obtain a given level of accuracy.

2. Rays (similar in concept to mathematical vectors) are cast out of the source antenna location and into the surrounding shipboard geometry.

3. Rays are allowed to bounce (reflect) off of surfaces, bend (diffract at geometric edges) and propagate optically through free space.

4. Each ray holds specific information (as a geometric vector would) to define the EM energy parameters of pointing direction, field intensity, polarization and phase.

5. An observer model (simulating the receiving antenna) is defined, and rays that intersect the observer model are captured.

6. The particular observer model then assesses the EM parameters associated with each ray and "absorbs" those rays as the actual antenna would respond to those EM field parameters.

7. Where an observer model performance parameter is affected beyond its design threshold (and therefore EMI has taken place), the field propagation parameters are analyzed to determine which ones have overriding effect on the results at the observer model.

8. Modifications are made to the geometric structure where significant ray interaction is taking place and then the process is rerun from step number 2 until acceptable performance of the system under investigation is achieved.

RAY TECHNIQUES DURING LHD 5 DESIGN

A recent example of the utilization of ray techniques in an ongoing ship design took place during contract design for LHD 5. Ray tracing was utilized to support redesign of the LHD 5 forward mast to minimize the effects that an off-ship (and therefore far field) jammer has on the AN/SPS-48E air search radar when near-by structures (near field clutter) reflect jamming energy into the antenna

PROBLEM STATEMENT

The ability of the AN/SPS-48E radar to operate in a jamming environment is detrimentally affected by structural elements around the antenna. LHD 5 forward mast has

5

multiple structural elements around the AN/SPS-48E antenna.

BACKGROUND

The AN/SPS-48E radar has been designed to operate when an off-ship jammer is attempting to "blind" it with EM energy of specific characteristics. The AN/SPS-48E has been designed to respond to the jamming energy by adjusting the radar's ability to receive any energy along a predefined search sector in the direction of the jammer. This response in fact removes the jammer's capability of affecting a large search sector of the radar coverage. Full capability of the radar is maintained along all other sectors of operation. When structure is located very near the antenna, enough jamming energy reflects off the structure to initiate the anti-jam response when the antenna is pointed away from the jamming source and at the reflecting structure. With many structures reflecting energy at the same time, on many different bearing angles, the net effect to the performance of the radar is that many search sectors are lost on many bearing angles thus reducing the radar's ability to perform detection functions on bearing angles other than the jammer bearing angle.

GEOMETRY

A solid geometry model of the LHD 5 was constructed from two different geometrical sources of data. First the Initial Graphics Exchange Specification (IGES) formatted output of the LHD 5 geometry model from NAVSEA's General Arrangement Design System (GADS) was transferred to the NAVSEA Electromagnetic Geometry Modeler (EMGEO) System. This made available to the EM engineer the basic structural model of the ship (decks, bulkheads, hull, superstructure) and major equipment locations. In EMGEO, topside equipments were replaced with equivalent topside equipments from the EMGEO data base which provided a higher geometrical resolution necessary for the analysis. The forward and aft masts were recreated with cylindrical elements to replace the flat plate approximation provided through the interface. This was necessary to allow the ray casting algorithm to accurately trace reflected paths from the masts' and yardarms' cylindrical elements.

APPROACH

The ray casting technique was utilized to "illuminate" the three dimensional geometric representation of the LHD 5 with very closely spaced rays. These rays represented energy arriving from a distant off-ship jamming source. Due to this distance, a plane wave front of ray energy was used to impinge upon the ship model. The casting direction of the rays was varied to analyze all possible reflecting geometries modeled. The program then computed each ray's new reflected trajectory utilizing geometric optic techniques. This process was then repeated for each ray until a bounce took the ray away from the geometry.

Once all rays were processed, those rays that passed through a spherical volume boundary (equivalent to the swing circle of the antenna face of the AN/SPS-48E) were captured for subsequent analysis. This subset of rays represents all possible reflective paths for EM energy from the off-ship source model to the on- board victim observer model, the AN/SPS-48E.

Next, the program analyzes the rays coming into the observer model to determine selective importance of a particular ray therein determining its ability to couple energy into the antenna itself. The rays are categorized by arrival angle (which is quite different from the initial direction of the cast ray). A measure of relative strength of the energy impinging on the antenna from any direction is represented as a function of the number of rays resident in each arrival bin (a bin defined as a small area of 1 degree square located on the observer model). Azimuth (AZ) and elevation (EL) data are also analyzed to estimate the effects the incoming rays will have on the antenna as it rotates. This requires the analysis to weight the relative contributions of incoming rays in a manner consistent with the "absorption" characteristics of the antenna itself. This is accomplished through use of the antenna far field gain pattern. This process is executed at each possible steered angle of the radar in AZ and EL as well as every possible angle of the jamming source in AZ and EL to obtain a complete set of data representing all reflecting structures in all cases of antenna operation.

It has been shown in previous shipboard measurements that reflections off a surface can be modified through shaping of the surface or through the application of Radar-Absorbent-Material (RAM). The ray techniques program allows for iterations with different shapes. It also allows for the application of RAM to a reflective surface thus rendering a perfectly reflective surface absorbent at an attenuation value consistent with currently manufacturable materials.

Initial runs of the ray casting program proved very lengthy on the available VAX based hardware. Reviewing initial results showed no reflective contributions from the flight deck of the model so it was removed from the analysis. Similarly all superstructure elements and equipment located below the AN/SPS-49 radar platform on the aft mast also had little effect on the reflective paths of rays that terminated at the AN/SPS-48E spherical observer antenna model. These reductions in the model geometry reduced the number of surfaces for rays to bounce off of and reduced the total size of the area onto which the plane wave of rays from the jamming source had to be cast. These two factors resulted in a decrease in the target area for the cast rays, and the casting density could

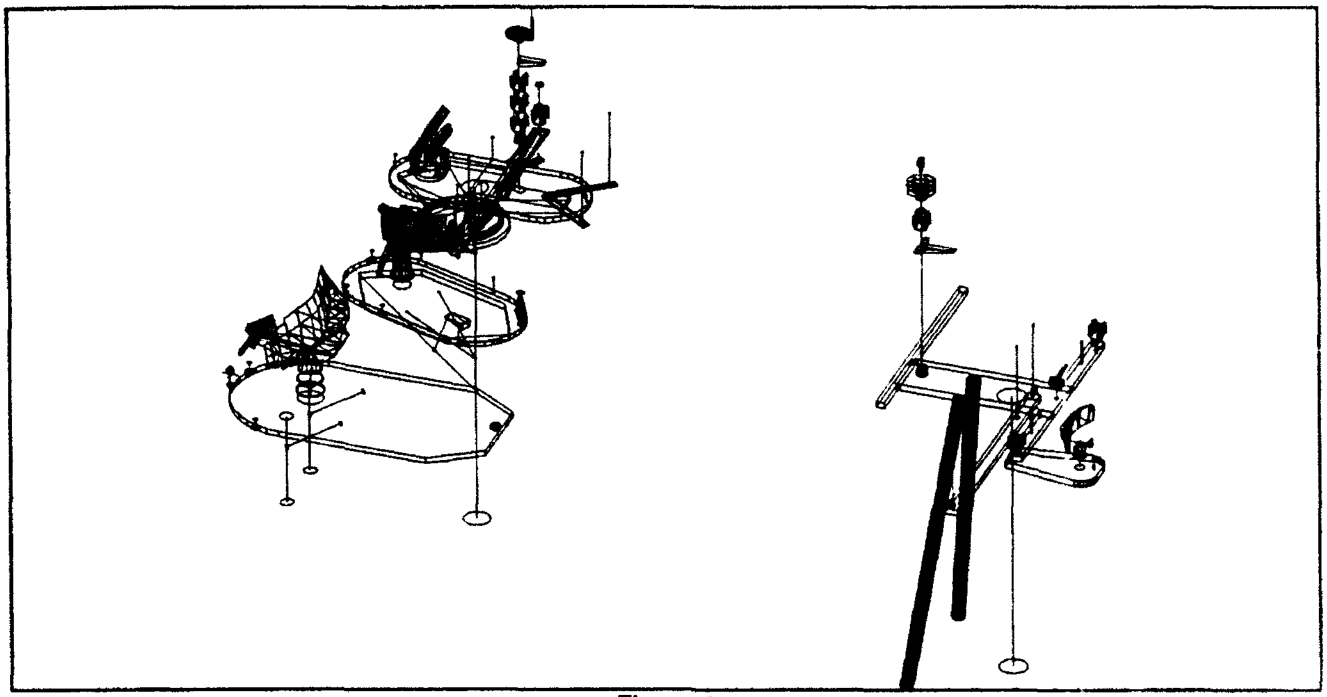

Figure 4

then be increased to explore the more critical areas of the topside structure. The total number of cast rays remained the same, but certain areas of interest were more finely illuminated with a local increase of ray density. Figure (4) depicts the geometry model used in all subsequent analysis runs.

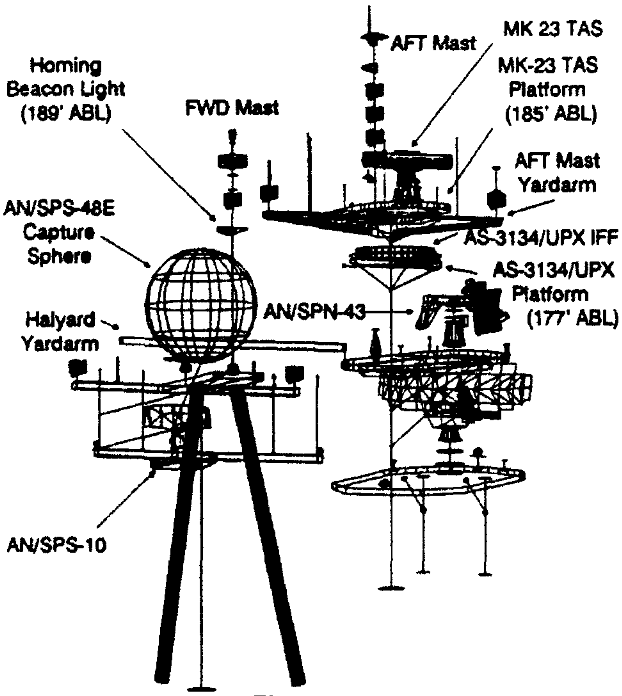

Figure 5

RAY CASTING

The observer model used to represent the AN/SPS-48E radar antenna was a sphere with a diameter of seventeen feet placed with its center at the midpoint of the antenna. Figure (5) depicts the sphere located on the forward mast of the LHD 5 model. Processing time for ray casting varies roughly as the number of geometry elements multiplied by the casting density. After a casting analysis is complete the engineer has the option to step through a view of the model and look at each ray individually that has reflected through the geometry and terminated into the observer model sphere. This capability greatly supports the engineer in visualizing the propagation paths. It also helps him in determining the validity of the results and of his geometrical representation of the ship itself.

Two different output plots are generated for each AZ and EL angle of the source jammer. An individual plot represents all the AZ and EL pointing angles of the observer antenna model itself. The first plot is a power density plot which depicts the total power density available at the observer antenna face. An example plot is shown in figure (6). The plot generated is a mercator projection of the rays energy content in specific capture bins (identified as black squares in AZ and EL). Energy content is represented in power terms of watts/meter^2 and is color coded to enhance the interpretation of significance of a particular angle so as to allow the engineer the capability to relook at the geometry model along particular ray angles of interest.

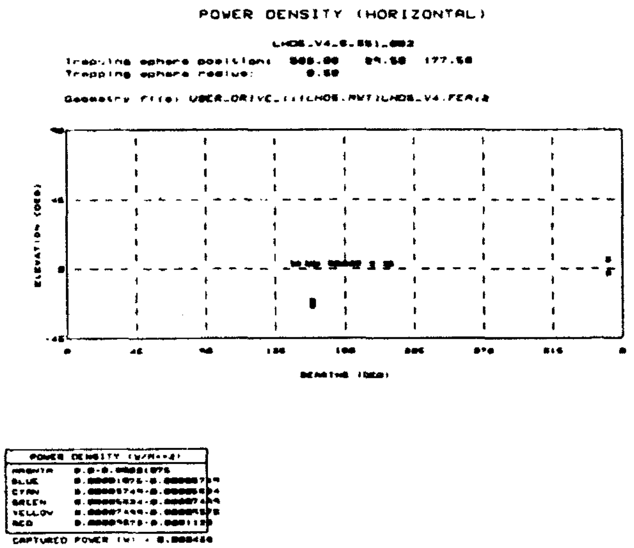

Figure 6

The second output plot is one of coupled power to the AN/SPS-48E. Here the EM energy components carried on each ray arriving from all directions are convolved (summing at each pointing angle of the observer model) with the antenna gain values. As the antenna rotates and elevates, the relative contribution of an individual intersecting ray will change and those changes are represented in the coupled power plot. Figure (7) shows an example of a coupled power plot. This plot is quite significant since the relative effects of geometric changes will show up on these plots as increasing or reducing the coupled power into the observer model. Relating this information to known thresholds of EMI for the AN/SPS-48E allows the engineer to control at least this portion of EM energy propagation to achieve EMC along with optimized combat system capability.

Exhaustive efforts go into assessing the tremendous amount of data obtained from the ray casting model. Geometric elements are identified that have significant contribution to the intensity of a particular bin in the coupled energy plot. Those geometric elements are then modified (by either changing their shape or reflective coefficient) and the process is run again. Figure (8) depicts a coupled power run under identical source conditions as figure (7). The only changes made were to the shapes of structures and the application of RAM. Tremendous improvements in decreasing the amount of coupled energy are shown by the darkening of the plot and reduction of "hot spots" shown as white to grey on figure (7) and now grey to black on figure (8).

RAY TRACING

Since ray casting only looks at the relative effects of reflection on a particular ray simulating EM propagation, a second ray technique called ray tracing had to be run to determine the contribution of diffracted energy on the overall summation of energy coupling into the observer antenna model. The ray tracing model allows an individual ray to diffract at a geometric edge and spatially spread the energy at the edge based on the uniform theory of diffraction. Two separate runs were made on the forward mast, one with reflective energy only and one with reflective and diffractive energy. Figure (9) depicts, on a three dimensional scale, the impact of reflected energy on the face of the antenna observer model given one source model location. The spikes in the upper quadrant identify the relative intensity of the energy at the antenna face. Figure (10) shows the impact of reflected and dif-

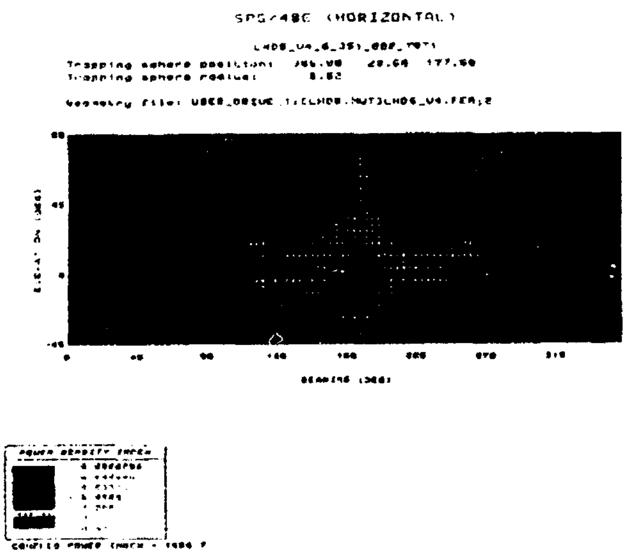

Figure 7

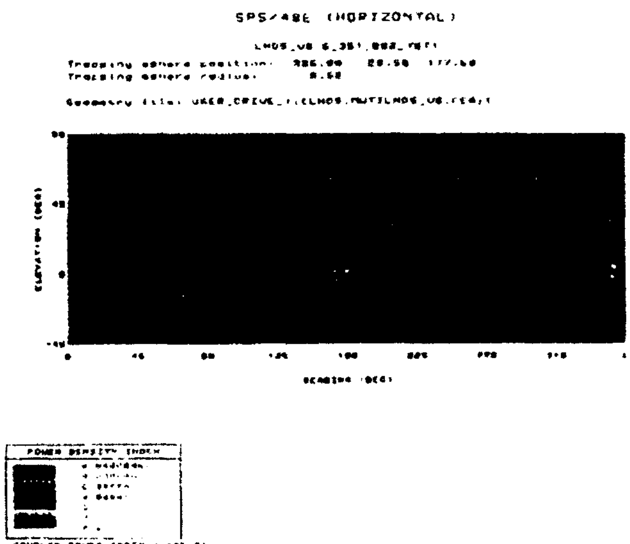

Figure 8

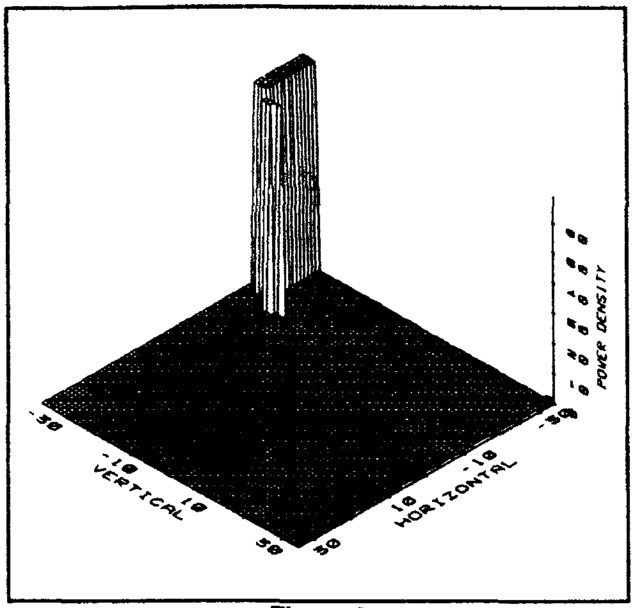

Figure 9

fracted paths combined. The number of energy paths (rays) has increased enormously. Many more rays are striking the face of the antenna over a much larger area. Yet, when the total power density at the face of the antenna for reflected and diffracted energy is compared to the total power density at the antenna for the reflected energy only, the difference is small in comparison to the thresholds of interference being predicted with the ray casting (reflective only) model. Therefore, for this analysis, it was determined that diffracted energy did not appreciably contribute to the results that were supporting the shaping and RAMing of structure to protect the AN/SPS-48E in LHD 5.

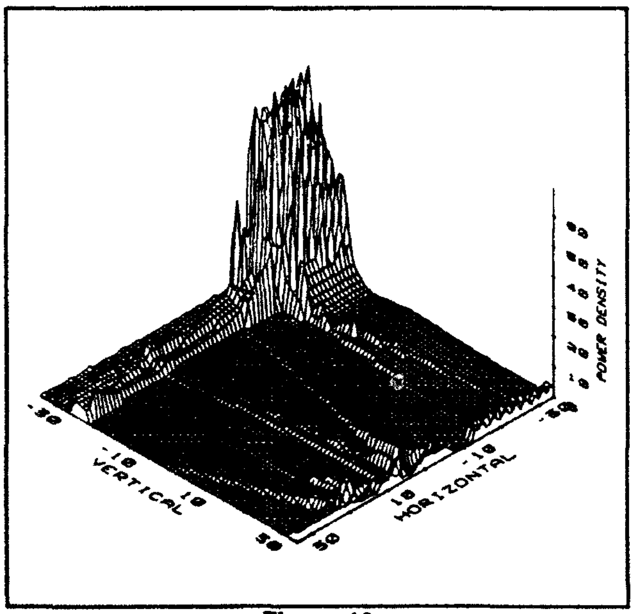

Figure 10

RESULTS

The entire analysis is documented in reference [5]. Below is an excerpt of actual design modifications based on reference [5].

1. The halyard yardarm on the forward mast was a major contributor to reflected energy at the observer antenna model. The close proximity of this yardarm to the observer antenna model enabled both the forward face and the top face of the yardarm to provide a reflective path. Ship design requirements prevented the removal or easy relocation of the yardarm without significant impact. Because of these factors, shaping was chosen to reduce the reflections. Sloping of the forward face of the yardarm downward 2, 4, 6, 8 and 12 degrees from vertical as well as modifications to a cylindrical yardarm were all assessed. Results confirmed that the 6 degree sloping face consistently produced the most favorable results although other configurations produced slightly better results at specific source angles.

2. The homing beacon light platform at 189' ABL on the forward mast acts as a plate reflector from some source model angles as well as an edge diffractor at nearly all source angles. The location of this platform above and directly aft of the observer antenna model makes it a particularly large contributor to energy received at the observer antenna model. Treatment of this platform with RAM reduced the contribution to negligible levels.

3. The forward pole mast as a large cylindrical element also provides a reflecting source. A vertically oriented cylinder will always provide a reflective spread of rays in the horizontal plane normal to the cylinder's axis. The application of RAM to this pole mast was necessary to reduce its contribution.

4. In addition the aft pole mast supporting the after mast platforms extending from 127' ABL to 185' ABL also proved to be a good reflector and required RAMing.

5. The forward vertical surface of the aft mast yardarm was also a contributor. This yardarm was part of the LHD 2 baseline design and since structural redesign of the yardarm itself was not deemed timely in the late stage of LHD 5 contract design, it was decided not to modify the yardarm shape itself. However, the creation of a non-structural metallic shield in front of the yardarm could obtain similar results to a structural reshaping of the yardarm. Since this yardarm was significantly aft and above the observer antenna model, an upward angle of 15 degrees from vertical was iteratively chosen. This provided maximum deflection of energy with minimum impact on the yardarm structure. Subsequent analysis of

source model angles revealed that the contribution from the after mast yardarm had been greatly reduced.

6. The forward edge of the aft mast platform at 185' ABL for the MK-23 TAS radar was reflective at most forward source model angles. Modifying the platform edge with a similar 15 degree upward angle from vertical was necessary to treat this reflection.

7. The forward edge of the aft mast platform at 177' ABL for the AS-3134/UPX IFF antenna ring also needed treatment. Since the geometric height of this platform relative to the observer antenna model was about equal, simple shaping proved difficult. Too small an angle would still reflect energy into the observer antenna model while too large an angle would reflect energy up into the bottom surface of the aft mast 185' ABL platform and back down to the observer antenna model (this is actually a two bounce pathway). Because of this condition, the installation of RAM was used to reduce the reflection.

8. The forward face of the aft mast platforms at 203' ABL supporting the aft masthead light and the aircraft warning lights also required treatment with RAM.

The results described above show design impact on the LHD 5, a paper ship soon to begin construction. Final validation of the design will not take place until LHD 5 goes through sea trials. The baseline ship used in the LHD 5 design was the LHD 2 (the first of the LHD 1 Class to get the AN/SPS-48E). LHD 2 trials will allow us to begin the confirmation process for the baseline ray technique runs used in LHD 5. Previous ship designs involving the AN/SPS-48E (e.g. CG 16 New Threat Upgrade) have been used to support the development of the ray techniques. In this way, lessons learned from previous designs can be incorporated into new ship designs at a time when modifications to the paper ship are far less costly than rebuilding existing masts on operational ships.

Future Challenges

There are many challenges awaiting our ship designers in the areas of design integration and EMI control. This section will describe some of those challenges and explain some of the steps being taken to meet those challenges.

Ship Topside Arrangement Configuration Management (STACM) Program

Within the ship topside arrangement process lies the task of maintaining control or managing a ship's topside configuration. In the past, there has not been serious effort, in the form of programmed funding, directed toward this management process. Consequently, ship alterations, and thus overhauls, have been more expensive than necessary because the actual configuration of the ship at any given point in its operational life is not known.

Often, during an overhaul, the same area on a ship will be planned for two separate functions. Or, conversely, areas are left vacant because a function was deleted and another was not identified to take its place. To prevent these occurrences and to provide the Fleet with improved combat readiness capability, the Ship Topside Arrangement Configuration Management (STACM) Program is being developed and will soon be proposed.

The STACM Program is structured to function within the framework of ship acquisition programs, the FMP and Warfighting Improvement Plans (WIP). It is a three-phased program which is described in detail in reference [1], and briefly below.

The Ship Logistics Managers (SLM's) and Class Design Agents or Expanded Planning Yards (EPY's) play very important roles in this program. Some of their responsibilities are defined in reference [6]. In addition, they must ensure early communication of existing and proposed changes to the topside configuration of each ship class so that the changes can be recorded in the appropriate data base. Their efforts along with the Topside Designer's are organized into a three-phased program of configuration management.

Phase I, called the **Configuration Reporting Phase**, involves the process of providing an up-to-date configuration baseline and maintenance of that baseline. Phase I establishes, or in some cases (i.e. when a new ship is delivered) validates, the first set of drawings, sometimes referred to as the Initial Class Baseline (ICB) drawings.

Phase II, called the **Configuration Planning (Near Term) Phase** involves incorporation of all K, D, and F SHIPALTS and Type Commander (TYCOM) issued alteration/improvement items that have been accomplished in the ship during periods between overhauls (or since development of the baseline). It also includes any type of proposed change for the ship's next availability. These items are to be incorporated into the configuration baseline drawings for the ship. With these changes incorporated into the baseline, the Topside Designer, TYCOM's and SLM's will have an idea of the ship configuration if all proposed or projected changes were accomplished during the ship's next availability. This set of drawings is referred to as the Projected Class Baseline (PCB).

Modifications which cannot be performed during the next availability will be moved into the next phase of configuration management: long term planning. At the completion of the ship's overhaul or industrial availability, the PCB's are updated to show how the work was actually

completed. The PCB's are redefined as the new ICB's, and the procedures of Phase II begin again.

Phase III of the STACM program is called **Configuration Planning (Long Term).** Long term configuration planning provides a long range planning tool for a particular ship or class. New systems under development are reviewed against the long range configuration baseline drawings. Long term configuration planning depicts the ship as far off into the future as one can envision, integrating all known or proposed changes. This set of drawings, referred to as the Future Class Baseline, is used by the SLM's to direct feasibility studies in support of long-range engineering efforts.

Through these three phases of configuration management, the SLM's, EPY's and Topside Designers will be able to ensure that arrangeable topside areas in each ship are used to the best advantage and in the most efficient manner possible in order to maximize mission effectiveness, supportability and survivability and minimize EMI affects.

Equipment Acquisition Process

If we are to significantly improve our ship EM performance and reduce costly after-the-fact corrective action, we must do a better job of integrating the equipment design with the ship design.

One of the reasons that EM equipment does not perform properly in ships is due to poorly defined requirements during equipment acquisition. The application and minimal enforcement of military standards, written as test and evaluation criteria, does not contribute to the definition of design requirements.

The equipment system engineer, the ship system integrator, the EMC engineer and people in other ship design disciplines must together develop the ship interface requirements necessary to ensure that the equipment operational requirements can be satisfied in the shipboard environment. The EMC engineer must define the real ship EM environment in performance terms vice test and evaluation. Strong support from the program office is required. EMC should be specified to be discussed at all design reviews, and the program office should ensure that appropriate EMC expertise, both equipment and ship, is available.

The preceding paragraphs are nothing new. It is just good systems engineering, specification writing and program management. One of our challenges is to ensure that appropriate EMC requirements are specified in performance terms which can be contractually invoked, are measurable and represent the real ship environment. We are making progress in this area but the emphasis must be improved. We are addressing only equipment types which have a significant EMI history. Equipment currently being developed in 6.2 and 6.3 R&D areas need to have EMC considerations included in their development. Electric propulsion, electromagnetic guns, and the electromagnetic catapult will be here in the not too distant future. Their design and procurement specifications must address EMC.

Accurate Databases

Another challenge is obtaining EM data that represents the real ship of today and that is current for its life cycle.

The STACM Program will help us track ship configuration but does not help with describing the EM environment. The real ship environment for which this information is required is not only the environment topside, primarily from combat systems, but below deck as well. Computer tools, blended with a solid measurement program, can fill the near term void; but a more comprehensive program needs to be developed. The EM Engineering Program, endorsed by the CNO, OP-03 and being executed in SEA 06, is making headway though consistent funding is limited. Navy laboratories, academia and industry must work together to develop the technology to predict and quantify the ship EM environment which the EM Engineering Program can then incorporate into tools for ship and equipment design and acquisition.

A library of topside element attributes is needed to provide the topside designers a quick reference for antenna and weapon system characteristics. We have started a data base of Topside Element Attribute Sheets (TEA Sheets) but have a long way to go to complete it. It must then be integrated into the topside design process so that it is easily accessible during the "placement of elements" task in the process.

The challenges presented here encourage the EMC engineering and ship integration engineer to become more creative, vocal and forceful to ensure that specifications include realistic ship environments and that requirements are not unduly waived. Configuration management programs must be initiated and enforced. With DOD taking action to reduce and control acquisition costs, our job is becoming more and more difficult, because we have to do more with less.

Summary

In this paper we have described a process by which an engineer can systematically attack the design of a ship's topside, and we have tried to present the reader with an appreciation of the complex EM environment that surrounds our Navy ships. We have described some of the

techniques (Ray Techiques), tools and processes needed to reduce EMI during the ship and equipment design processes. We have shown some of the improvements that can be made in the Fleet and have described a program of configuration management that should help reduce the cost of ship overhauls. Challenges for our future engineers and designers in the area of EM engineering for both topside integration and equipment acquisition have been proposed. Only after these challenges have been met can we be assured that our ships are designed to maximize overall ship performance in meeting mission requirements.

References

[1] Juras, J. and D.R. Cebulski, "Ship Topside Integration and Electromagnetic Interference Control", presented to the Chesapeake Section of SNAME, 8 May 1990.

[2] James F. Garret, Robert L. Hardie, and P.A. Rogers, "Let's Design Out EMI", Naval Engineers Journal, February 1982.

[3] Charles J. Gallagher, Jr., "Control of the Topside Electromagnetic Environment", Naval Engineers Journal, May, 198?.

[4] B. J. Cown, "Antenna Pattern Performance and Coupling in the Presence of Near-Field Shipboard Multiple Obstacles", Final Technical Report, Project A-3364, Georgia Institute of Technology, July, 1984.

[5] LHD-5 Class Ray Tracing Analysis, Final Technical Report, prepared by Rockwell International Corporation under contract N00024-89-5648 to Naval Sea Systems Command, August, 1990.

[6] Fleet Moderization Program (FMP) Management and Operations Manual: SL 720-AD-PRO-010.

DAMAGE CONTROL - THE LAST LINE OF SHIPBOARD DEFENSE AND THE GUARDIAN OF SUSTAINED MISSION CAPABILITY

Stanley Herman
Director
Damage Control and Safety Division
(SEA 55X2)
Naval Sea Systems Command

Christopher Loeser
Head
Damage Control Branch
(SEA 55X22)
Naval Sea Systems Command

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Abstract

The concept of shipboard damage control has been with us ever since that first seafarer decided to shed his ties to the land. When the early "ships" put to sea, the natural environment took its toll on the best of craft. With no readily available repair facilities, those early ships were on their own, and elementary damage control procedures were required to maintain some degree of seaworthiness. When early naval strategists realized that waterborne craft could be used to gain military advantage, shipboard damage control took on a new meaning as vessels "sailed into harm's way". Shipboard damage control had now become a survivability issue, and "Save the Ship!" was the main concern. This philosophy had served us well, up to and including WWII, Korea and Viet Nam.

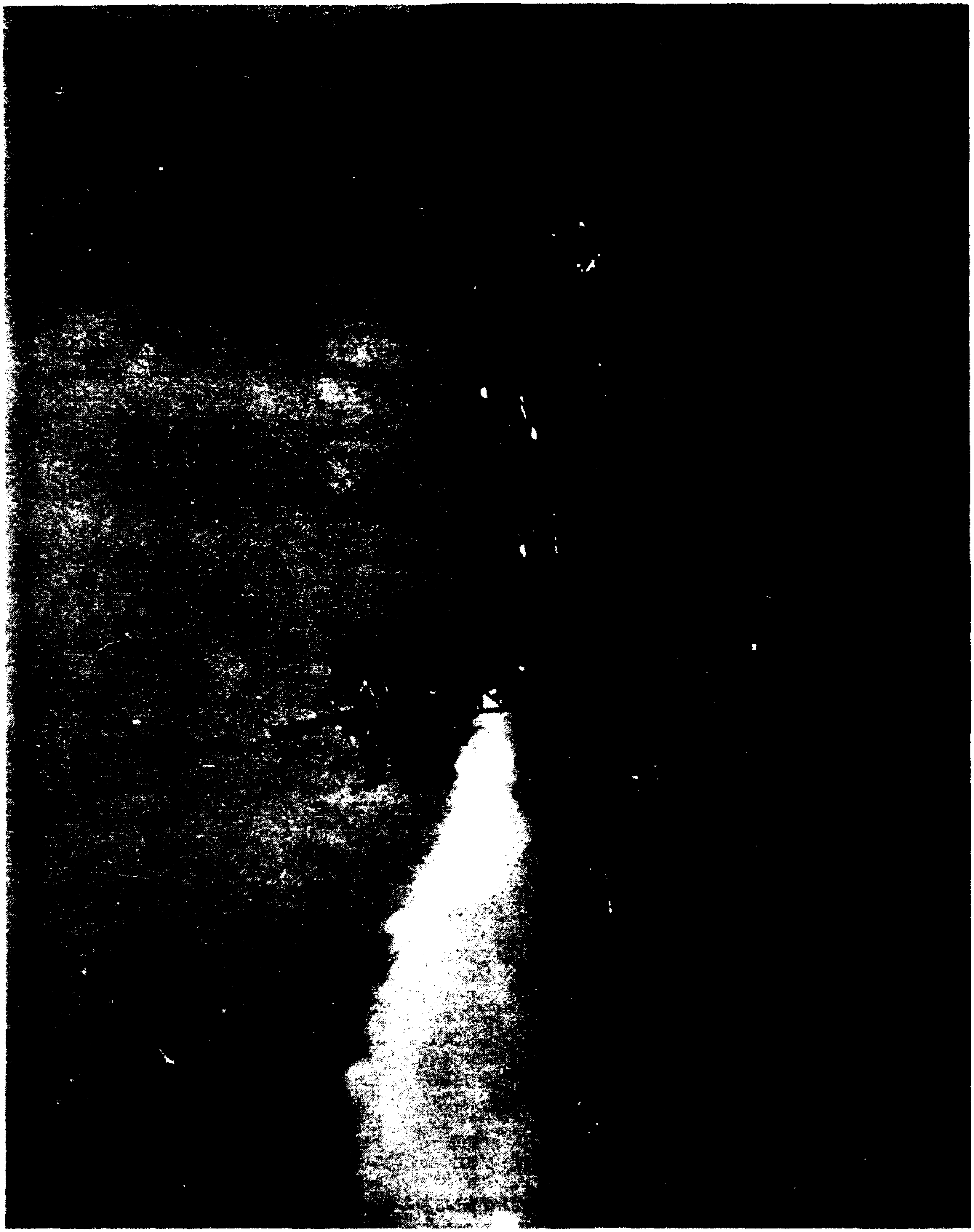
With today's modern and complex ships, and the rapid pace of the potential battle scenarios, the ability to "fight hurt" is the new order of the day. Modern ship, systems and equipment designs, operational doctrine and training must be configured to afford rapid and effective response to a host of new threats. This is especially true in the area of shipboard damage control where the ability to effect rapid restoration of vital systems becomes as important as the basic philosophy of saving the ship. "If you cannot shoot back, your enemy will not wait until you can!"

Figure (1) is a chilling reminder of the devastation that today's modern weapons can wreak on our ships, and it underscores the necessity of achieving a high order of damage control proficiency with respect to design, doctrine and training.

This paper addresses the ship, system and equipment design features, operational doctrine and training that has been developed to provide effective shipboard damage control. Both the ship and the sailor are addressed, since both are integral and interdependent components of the damage control "system". Also, the enhancements afforded to protection of personnel from the effects of conventional and nonconventional weapons are discussed. Finally, a brief look into the future is presented. With the shrinking defense budget and corresponding reduction in fleet size and ship manning, novel system designs and automated decision aids will be required to do the job.

ABBREVIATIONS

CBR	Chemical, Biological and Radiological Defense
CPS	Collective Protection System
DC	Damage Control
DCA	Damage Control Assistant
DCC	Damage Control Central
DCPOOW	Damage Control Petty Officer of the Watch
DCRS	Damage Control Repair Station
DCUL	Damage Control Unit Locker
DCUPS	Damage Control Unit Patrol Station
EEBD	Emergency Escape Breathing Device
FCCS	Flooding Casualty Control System
FFBA	Firefighters Breathing Apparatus
FFE	Firefighters Ensemble
FZ	Fire Zone
IC	Interior Communications
ISMS	Integrated Survivability Management System



JP5	Jet Propulsion Fuel No. 5
MOPP	Mission Oriented Protective Posture
NSTM	Naval Ships Technical Manual
OBA	Oxygen Breathing Apparatus
PECU	Portable Exothermic Cutting Unit
PHARS	Portable Hydraulic Access and Rescue System
PMS	Planned Maintenance System
PQS	Personnel Qualification Standard
PZ	Pressure Zone
RADIAC	Radiation Detection, Indication and Computation
WIFCOM	Wirefree Communications

FIGURES

INTRODUCTION

The objective of shipboard damage control (DC) is to achieve the highest potential of maintaining operational readiness and to preserve the warfighting capability of the ship, both in hostile and peacetime environments.

Damage control includes all procedures, ship design features and on-board equipment necessary to minimize and contain the effects of casualties; restore vital Hull, Mechanical and Electrical services; improve stability; exclude and decontaminate chemical, biological and radiological (CBR) agents and protect personnel.

In order to determine the extent of damage, and the degree of damage control required, it is necessary to consider the "threat". Unlike many other disciplines concerned with ship design, Damage Control must regard this "threat" to be caused by events occurring both during peacetime and battle conditions. The threats can range from enemy weapons to sloppy housekeeping. Either way, ship design, support equipment, doctrine and training play a vital role in coping with the inevitable damage that will occur, and a rational philosophy must be applied in order to achieve a reasonable balance of capability vs cost.

The threat ranges from enemy missiles, bombs, mines, torpedoes (conventional, nuclear, chemical and biological) to shipboard incidents caused by malfunctioning equipment, collision and improper procedures, and, finally, to the basic nautical environment itself, the sea. However, the effects caused by the threats can be categorized in a more structured manner:

Primary weapons effects: Blast, fragmentation, shock, envelopment by nuclear, chemical, biological agents.

Secondary weapons effects: Physical damage to structure and equipment, flooding, fire, heat, smoke, explosive gas, toxic atmosphere.

Impact on ship and systems: Loss of buoyancy, stability, structural integrity, combat capability, mobility, protective systems, personnel and equipment.

In order to more easily discuss the subject of damage control, we can separate the discipline into distinct phases, all of which are intimately interrelated, and each of which plays a significant role. The phases are:

- Ship design
- DC Equipment Design
- DC Doctrine
- DC Crew training

SHIP DESIGN

The ship is designed to afford a certain degree of protection against the threat. The DC philosophy is to provide barriers, containing the threat effects, within a volume that can be managed by ship's force. Since casualty growth is a dynamic process (for example, unchecked fire growth occurs exponentially with time), DC systems and equipments must be designed for expediency of use. Also, since weapons effects/accident induced casualties can cause many different types of simultaneous damage, DC hardware and procedures must be appropriately configured.

Many survivability features tend to add complexity to ship operation. In order to improve operability under low threat conditions, ships are designed to utilize material conditions of readiness by which the crew can tailor the

degree of protection to the anticipated threat. Basic survivability principles are incorporated into the ship design, and include segmentation, separation, redundancy, limitation of cross-section, multiple connections and minimization of internal contamination.

Segmentation: Vital systems are designed so that when the threat probability is low the systems can be operated as a single system with a minimum number of prime movers (pumps, generators, etc.). When the threat probability is high, the systems are segmented into two or more independent systems, minimizing the probability that the entire system will be lost with a single weapon hit.

Separation: Major components of segmented systems, such as pumps and generators are separated by a distance equal to the expected "length" of damage so that two redundant components are not damaged by a single weapon hit. In addition, repair stations are separated by a distance equal to the appropriate length of damage. Alternate repair stations are located port and starboard. Piping or cable paths to a vital component are separated and fed by sources at points separated by a distance equal to the appropriate length of damage.

Redundancy: To prevent loss of system capability, redundant components are included. For example, repair stations are redundant components. Redundancy is also provided within segments, for example, each segment of the firemain may be supplied by two firepumps.

Limitation of cross-section: Non-vital portions of systems are isolated from the mains during conditions of high threat probability to reduce the exposed cross-section of the system.

Multiple connections: Providing multiple connections between redundant portions of a system improves the ability to reconfigure the system, thus bypassing the damage. Figure (2) shows how a typical firemain is configured to reflect these features.

Minimization of contamination within the ship: Design efforts pursue two objectives simultaneously: minimization of shipboard deposited (CBR) contamination, and mitigation of the effects of residual hazards. Deposition of (CBR) agents on ship topsides are reduced through judicious use of the installed water washdown system. Infiltration of (CBR) agents into the ship can be reduced via minimizing openings in the weather boundary and by judicious positioning of weather openings. A more effective technique seen on our newer ships is the Collective Protection System (CPS), which provides a contamination free environment to selected internal areas of the ship. This eliminates the need for personnel within the protected boundary to don CBR protective clothing and breathing equipment. Another function of the CPS is to provide a "safe haven" for personnel who had been "suited up" during the CBR attack, and who now need to doff their protective equipment for rest and recuperation in order to return to battle stations. Figure (3) illustrates the concept of CPS on a modern destroyer.

Boundaries are provided to contain the spread of damage. Watertight, airtight and fumetight boundaries are designed to contain flooding, fire, smoke, toxic and explosive gases. Since there are several types of boundaries, and because boundaries restrict movement and complicate system installation, boundaries are generally superimposed. For example: Transverse CPS pressure zone boundaries generally coincide with fire zone boundaries. The major boundaries are the DC deck (ie., the lowest full length deck in she ship that has access throughout the length of the deck), the main deck, vital space boundaries, the first deck or platform above the keel, the main transverse watertight bulkheads, the firezone boundaries and the CPS boundaries. Figure (4) illustrates some of the major boundaries.

In order to deal with loss of ship systems, damage control requires independently powered equipment. For example: lighting in critical areas is provided with battery backup; communications is provided with sound powered phones and battery powered wirefree communication systems as backup; the JP5 powered portable P-250 pump is provided to back up the firemain.

DC systems are designed to be readily available and understood, easy and safe to operate, and capable of providing immediate feedback on proper operation. DC systems located in areas of the ship that may be inaccessible due to flooding, fire, smoke or damage, are provided with remote operators. DC system controls are centralized in order to reduce the number of personnel needed to use the system, to increase the speed of response, and to minimize communications problems. For example, DC actuators and controls are located on the DC deck in order to afford remote control of vital systems. Accesses to these controls are designed to ensure rapidity in setting of material conditions, movement of personnel to battle stations, locating DC system controls and retrieval of DC equipment. Provision is made to afford escape from, and the ability to reman, vital spaces below the Flooding Water Level I after flooding has occurred. Access is provided to the DC Repair Stations from above to allow retrieval of equipment when casualty conditions have forced personnel from the repair station area.

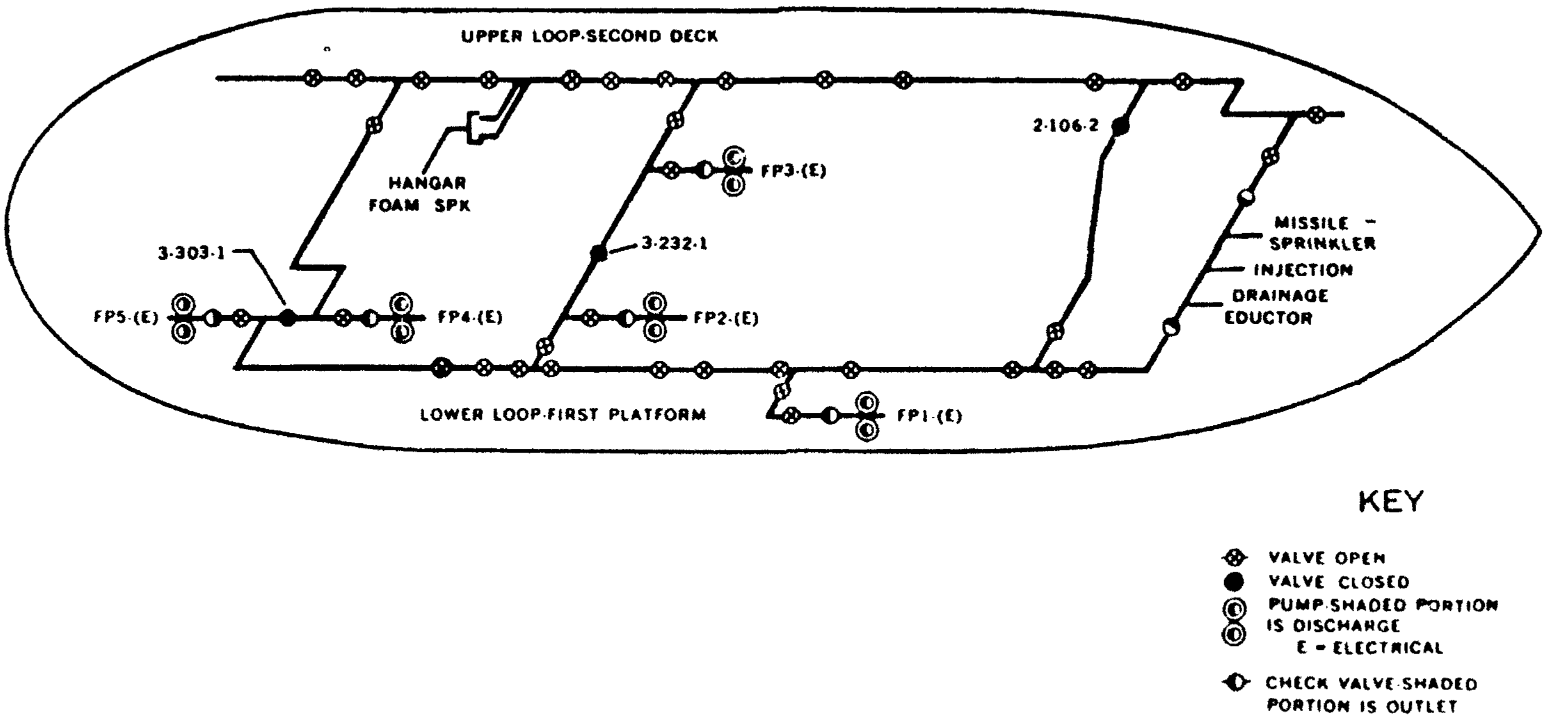


Figure 2 FIREMAIN SEGRATION (CONDITION ZEBRA)

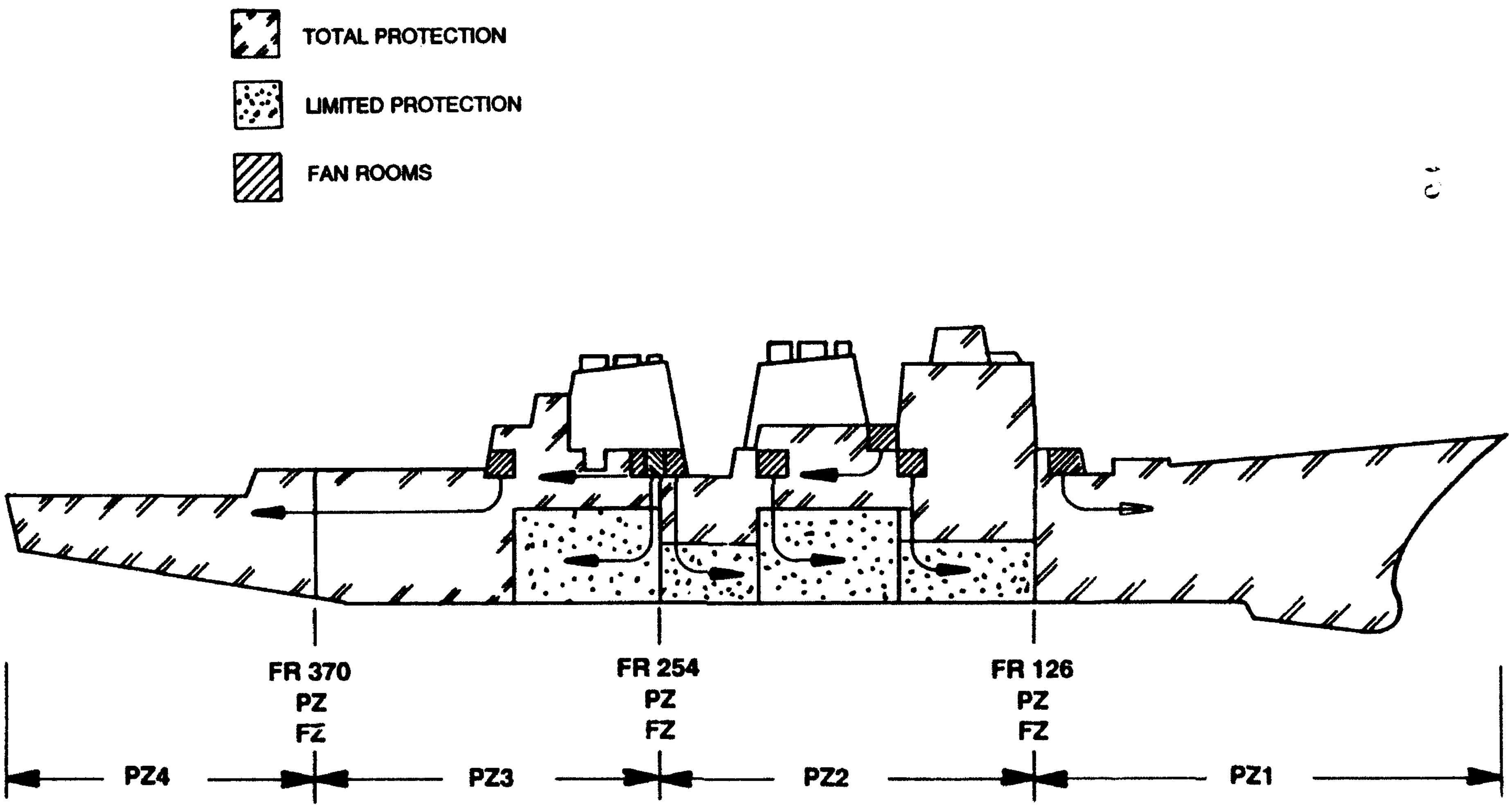


Figure 3 FULL-TIME COLLECTIVE PROTECTION SYSTEM (CPS)

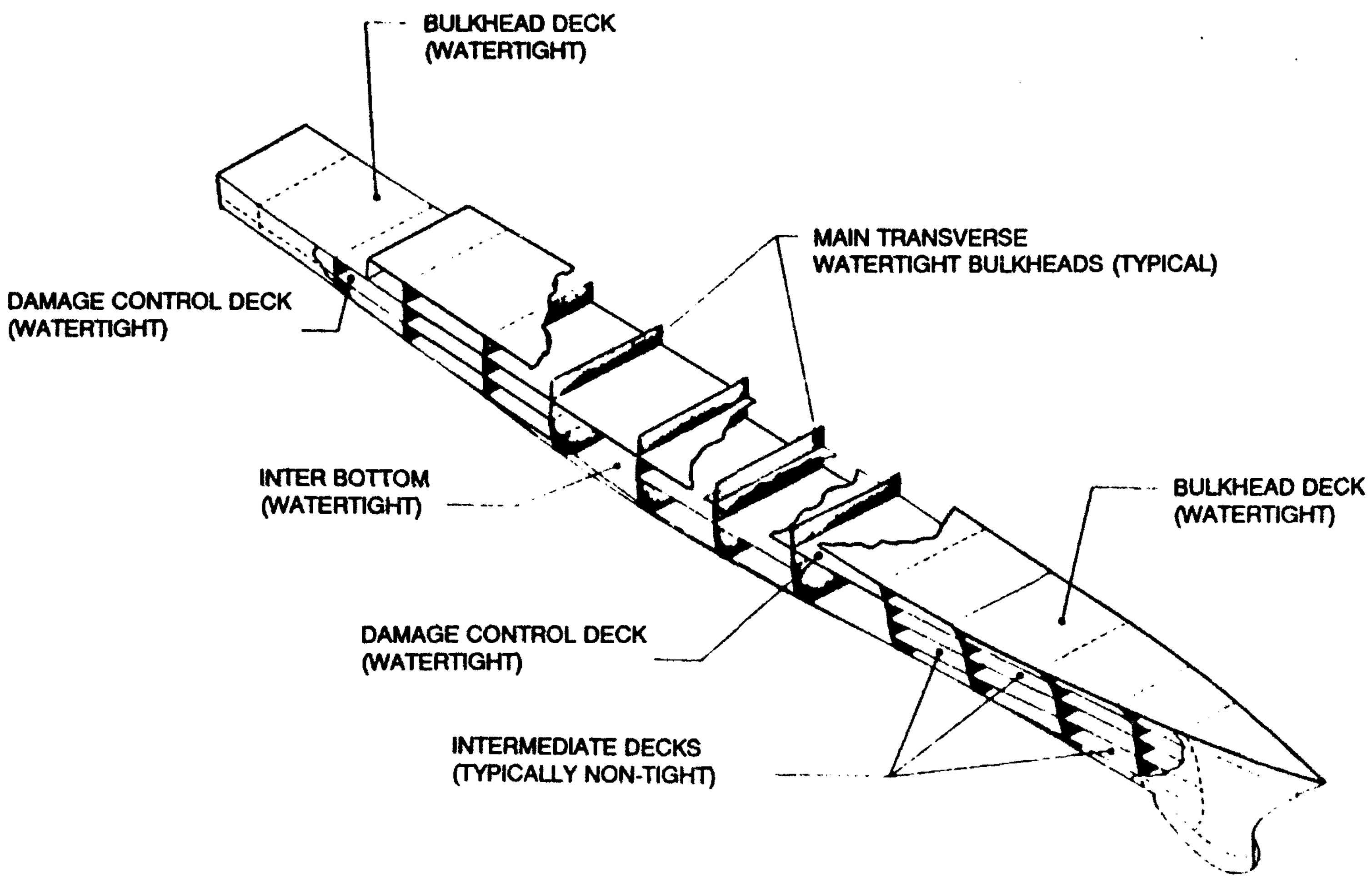


Figure 4 WATERTIGHT BULKHEAD AND DECK LOCATIONS

Valves and fittings are strategically positioned to insure operation under ship damage conditions. Valves required to secure open piping paths are located at bulkheads to minimize the length of unprotected piping between the valve and the bulkhead. Access and ventilation openings with closures in main transverse watertight bulkheads are located relatively high in the ship, above the DC deck. This minimizes the chance that an open door will be present to allow progressive flooding, and increases the probability that the door will be accessible when damage occurs.

Ventilation openings (without closures) in main transverse bulkheads are designated only above the Flooding Water Level I on main transverse watertight bulkheads to preclude an unprotected path for progressive flooding. Ventilation openings in the main deck are located inside Flooding Water Level II to preclude an unprotected path for downflooding.

Systems are located such that, if damaged, they do not damage other systems. For example; fire main components are not located in electronics spaces, and fuel oil piping does not pass through ammunition spaces.

Most DC spaces and associated personnel and equipment are protected by their location on the watertight DC deck and beneath the watertight main deck. Personnel trained in investigation and in immediate response to a casualty are located in each main watertight subdivision so that the entire ship can be investigated without having to violate the integrity of the main transverse watertight bulkheads. Designated DC spaces include:

Damage Control Central (DCC): Designed to provide shipwide damage control coordination. DCC includes space for displays used to plot damage and damage control activity, for alarm displays and for system management displays. Space is provided to phone talkers for all monitored circuits, the DCC supervisor and plotter. DCC is centrally located in a protected area within the ship. On small ships DCC is located on the DC deck, and on larger ships DCC may be located lower in the ship where more protection is afforded.

Damage Control Repair Station (DCRS): Designed to provide coordination for broad areas of the ship. The DCRS incudes volume for a display used to plot damage and damage control activity, for the supervisory and communications personnel stationed within the DCRS and for stowage of DCRS tools and equipment. Volume in the vicinity of the DCRS is provided for the DCRS personnel stationed outside the DCRS and for additional tools and equipment. Usually several of these stations are installed on the ship in order to obtain redundancy, for fighting multiple casualties and to ensure that a reasonable coverage of the entire ship's volume. The DCRSs are located on the DC deck or above.

Damage Control Unit Patrol Stations (DCUPS): Support the DCRS and the Damage Control Unit Lockers (DCUL). A DCUL is installed in each watertight subdivision which does not contain a DCRS, has minimal capability, and is primarily for investigation, initial response and boundary setting. Space is provided for 12 persons. In areas where there is a high potential for damage and is not easily accessible from a main DCRS, a DCUPS is installed. The DCUPS is larger than the DCUL, and is designed to support sustained response to a casualty.

Rescue and Assistance/Topside Repair Station: Provides stowage for equipment to support damage control efforts on other ships and reentry of own ship when the interior has been rendered untenable by smoke or fire. The Rescue and Assistance/Topside Repair Station is unmanned.

Crash and Salvage Lockers: Installed to provide flight decks with firefighting equipment for fighting aircraft fires.

Machinery Space Damage Control Kit: Area is provided to each machinery space to stow this kit, which provides rapid response to main engineering space fires.

DC equipment maintenance and training space: Areas are provided to support these functions.

Personnel Decontamination Spaces (DECON): DECON stations are strategically placed throughout the ship to afford decontamination of personnel who have been exposed to toxic agents. The spaces are designed to allow contaminated personnel to enter via the weather, doff their contaminated clothing, shower/ decontaminate, and exit into uncontaminated ship areas. Figure (5) illustrates a typical DECON space. Figure (6) shows other DC spaces on a modern destroyer.

Stowages for DC equipment are designed to insure that equipment required for the initial reaction is readily available and that all equipment is arranged by function. In general, personnel and equipment are dispersed throughout the ship within the area of responsibility of each repair station to expedite investigation, hasten the deployment of equipment, and improve survivability of personnel and equipment. The stowages are separated, and are spread within the repair locker area of responsibility to reduce vulnerability. Access from within the repair station is provided to the weather to allow reentry

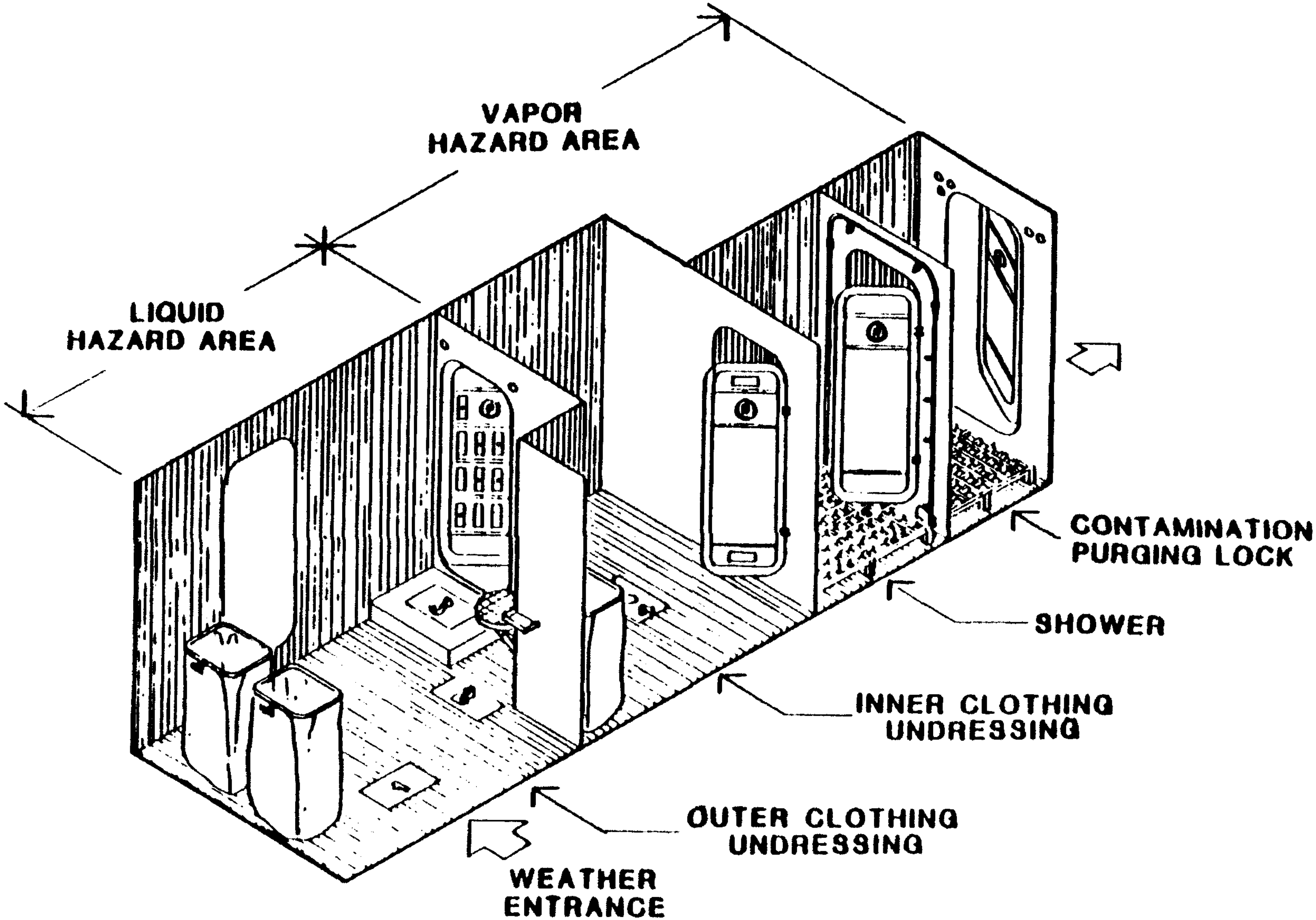


Figure 5 PERSONNEL DECON STATION (CPS SHIPS)

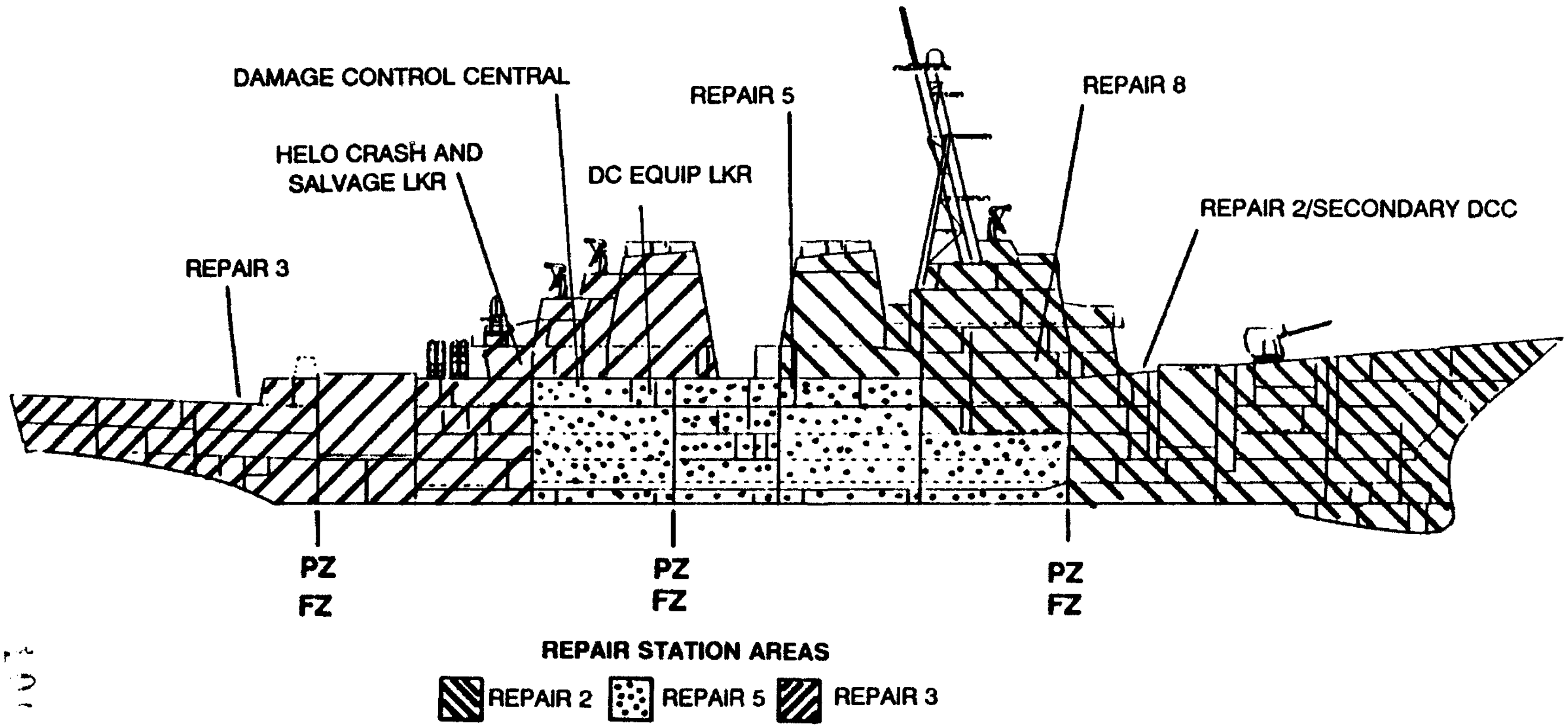


Figure 6 DAMAGE CONTROL FEATURES

after personnel have been forced to evacuate the interior of the ship. Proper identification and stowage of portable and fixed damage control support equipment is designated.

In order to improve speed of response, minimize operational error and simplify training, standard numbering and identification systems that define function and location of fittings supporting damage control are incorporated. Also, DC fittings are identified according to material condition of readiness.

Use of combustibles in design is minimized. Stowage of easily combustible material is tightly controlled. Systems are designed utilizing noncombustible materials, such as non-flammable hydraulic oil for hydraulic systems. Juxtaposing hazardous areas is avoided; for example, a magazine would not be located above a main machinery space.

Sensors are installed in order to ensure that casualty/CBR data reaches the damage control organization as quickly as possible. Dedicated communications are provided to transmit casualty status information to and from Command and on scene DC personnel. Included in the ship design package are vital DC technical documentation and drawings. The most critical include:

DC Book: Aids in managing damage control activities. The book provides information about shipboard systems and stability which can be used by the Damage Control Assistant (DCA).

DC Diagrams: Installed in the repair station for manning the DC situation by plotting casualties and damage control actions. The diagrams show the ship's arrangements, compartment names and numbers and the location and number of the doors and hatches. The diagrams also depict the ship's systems superimposed on the arrangements giving a clear picture of the system configuration and the location of the DC valves.

DC EQUIPMENT DESIGN

DC equipment is designed to provide the maximum capability, safety of operation, and portability, have a long shelf life, and be as uncomplicated as possible. Equipment is designed to have high reliability under extreme environments, reduced required maintenance and training, and reduced possibility of error when operated in a casualty environment. Other design considerations include:

lightweight
minimal size
minimum number of sizes
minimum procurement time
simplicity
multiple use
compatibility of operating fluids
commercial availability if possible
complete technical documentation/instructions for use
fire retardancy of packing materials
minimum disruption to personnel performance

DC equipment is designed to mitigate, control, or protect equipment and/or personnel from the effects of:

CBR agent intrusion: Personal protective equipment provides individual protection with minimum disruption of task performance. Typical equipment includes masks, suits, gloves, boots, detector paper, special drinking aids. Figure (7) illustrates the standard issue CBR-D protective clothing and mask.

Fire: Portable fire fighting equipment extinguishes fires by cooling, by removing oxygen and by interrupting the catalytic process. Firefighting personnel protection equipment provides life support environment (including protection from heat, flash, toxic fumes, flame, missile hazards and hazardous liquids) during all stages of firefighting, while causing minimal discomfort and task disruption to the wearer. Typical equipment includes the firefighter's ensemble (FFE) (suit, helmet, gloves, boots and flash hood), thermal imager and the oxygen breathing apparatus (OBA). Figure (8) shows the FFE and the OBA.

Flooding: Portable equipment improves stability and buoyancy by dewatering compartments after flooding has been controlled. Independent sources of power for prime movers is a design feature. Typical equipment includes the P250 portable pump, and the portable eductor.

Smoke: Equipment supports rapid desmoking of compartments. Independent sources of power for prime movers is a design feature. Typical equipment includes the electrically driven low and medium capacity, low pressure desmoking fans and the water driven high capacity, high pressure desmoking fan. The portable smoke curtain and smoke blanket provide a readily made barrier to contain smoke spread, and still allow access by firefighters and their equipment.

Power disruption: Simple yet efficient equipments provide means of restoring vital systems via cable repair, use of electrical casualty power system, pipe patching, jumpering and interfacing with the casualty sound powered phone system.

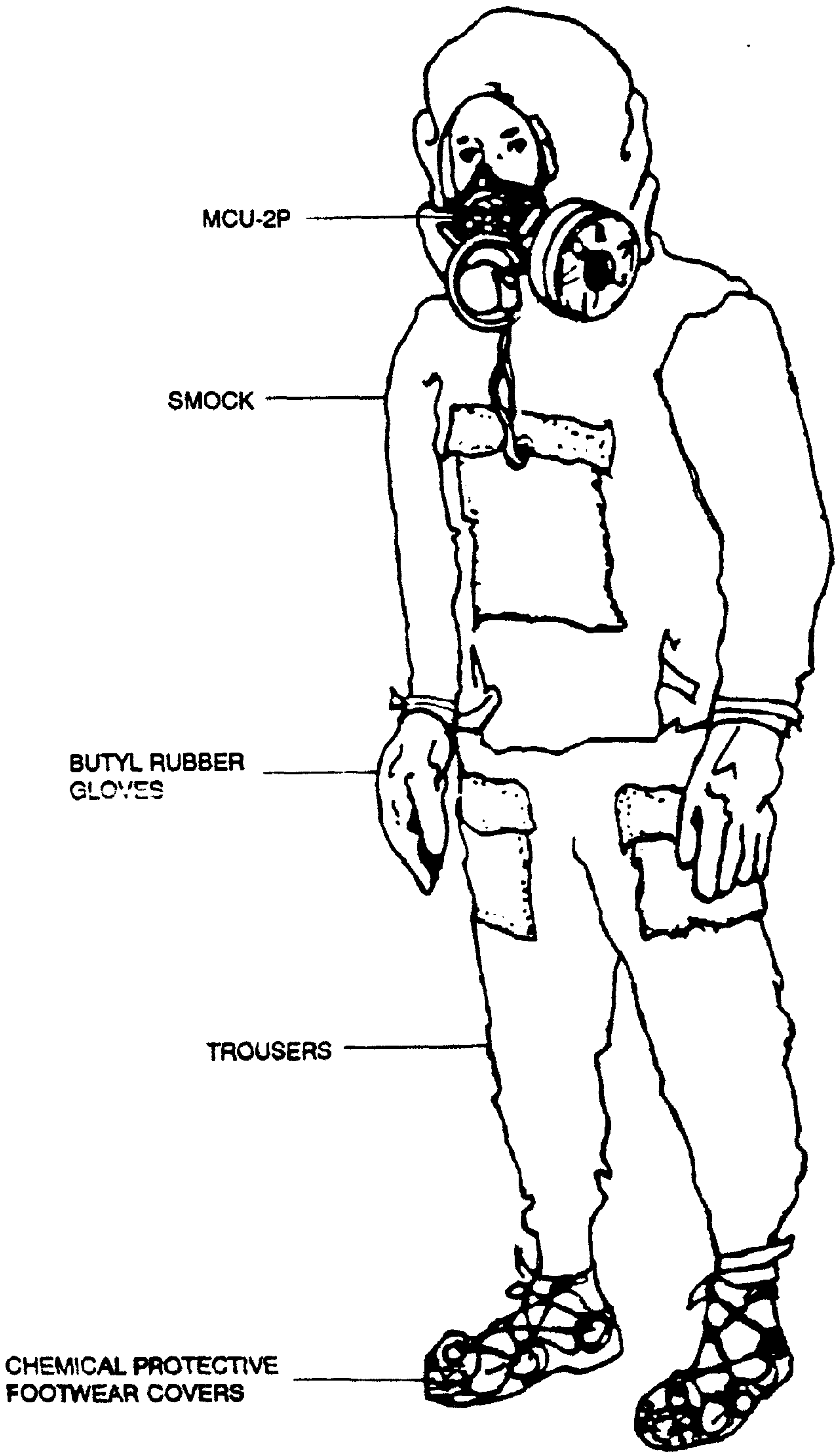


Figure 7 CHEMICAL PROTECTIVE OVERGARMENT

Figure 8 FIREFIGHTER'S ENSEMBLE AND OBA

Compromise of boundary integrity: Equipments maintaining integrity of passive boundaries by cooling fire boundaries, shoring and patching flooding boundaries, and plugging piping systems that penetrate boundaries. Typical equipment includes pipe patching devices, wood and steel shoring members and associated fittings and steel plating.

CBR contamination: Personal protective equipment provides individual protection to personnel who may be exposed to contamination. Typical equipment includes masks, suits, gloves and boots. Chemical detection kits and radiation detection, indication and computation devices (RADIACs) provide the means to detect and monitor contamination. Decontamination kits are provided to decontaminate both personnel and equipment. Ships carry calcium hypochlorite that, when mixed with sea water, is used to decontaminate ship surfaces and equipment.

Toxic/explosive environments: Portable equipment prevents asphyxiation while escaping from fire, smoke or fume filled environment by providing positive pressure breathable air in a package that has a long shelf life, is easily donned and that allows sufficient time for escape. The emergency escape breathing device (EEBD) is the primary unit issued to the fleet, and it has proved itself countless times in saving lives. Equipment is provided to detect toxic gases and explosive hydrocarbons that may be present due to a casualty.

Falls: The climber safety harness supports personnel engaged in activities while aloft.

Man overboard:

Hypothermia: Wet and dry suits reduce the loss of body heat from personnel in the water. These suits are required to be worn during specific operations as determined by local command.

Drowning: Risk of drowning is significantly reduced by providing a life vest which not only provides adequate buoyancy, but is also self righting to preclude ingestion of water.

Burns/excessive heat:

Firefighting personnel: Two-level protection is provided; (a) the FFE, as mentioned above, for entering extremely hot spaces, and (b) layered protection for the supporting firefighters. Fire retardant coveralls are provided as added protection for repair station personnel who support firefighting efforts. Long sleeved, turtlenecked jerseys, cranial helmets with goggles and leather, and non-sparking shoes are provided for flight deck firefighters to allow continuous firefighting operations in the flight deck environment. Aluminized proximity suits are provided for selected flight deck personnel to enable firefighting close to the fire. The flash hood and gloves are designed to prevent burns from explosions and flashovers, and are provided to personnel at general quarters.

Normal working personnel: Fire retardant clothing, consisting of trousers, long sleeve shirt and leather shoes, are provided for working personnel to allow only 20% body burn from a two-second 2000 degree flash fire.

Fragmentation and projectiles: The ballistic vest is provided to protect the critical core body areas allowing operation in a high threat environment in situations where personnel mobility outside of a protected enclosure is required. Hard armor (ceramic or steel) inserts are provided to protect against armor piercing threats.

Equipment is grouped into kits by function, and is designed to be readily moved from its stowage location to the casualty. All of the items required for operation; for example, safety glasses and gloves for plastic pipe patching, are included in each kit. The number of separate components required to be carried to the scene is minimized by grouping components into easily carried units.

DC DOCTRINE

In order to conduct effective shipboard damage control, an efficient and effective organization must be in place. The ship is organized to maximize the effectiveness of dealing with the threat effects. A typical organization for a combatant ship is shown on Figure (9). The positions and responsibilities of this organization are clearly defined on the battle bill. Each position is manned at the appropriate skill and experience levels, and the positions are manned when an emergency occurs or when "General Quarters" is sounded. The DC management process begins when it has been determined that a threat is present, and increases in intensity when the battle organization has been put into place. When a casualty, or its effects, is observed, casualty data is passed to the local damage control station and then to the central damage control station. At each stage the data is analyzed, courses of action are proposed and selected, and action is directed. The DC manager must also monitor the casualty.

Effective use of the DC assets is essential. The first, and foremost objective is to maintain readiness. Then, when damage does occur, ship's force will be in the best posture to deal with the damage. All possible survivability en-

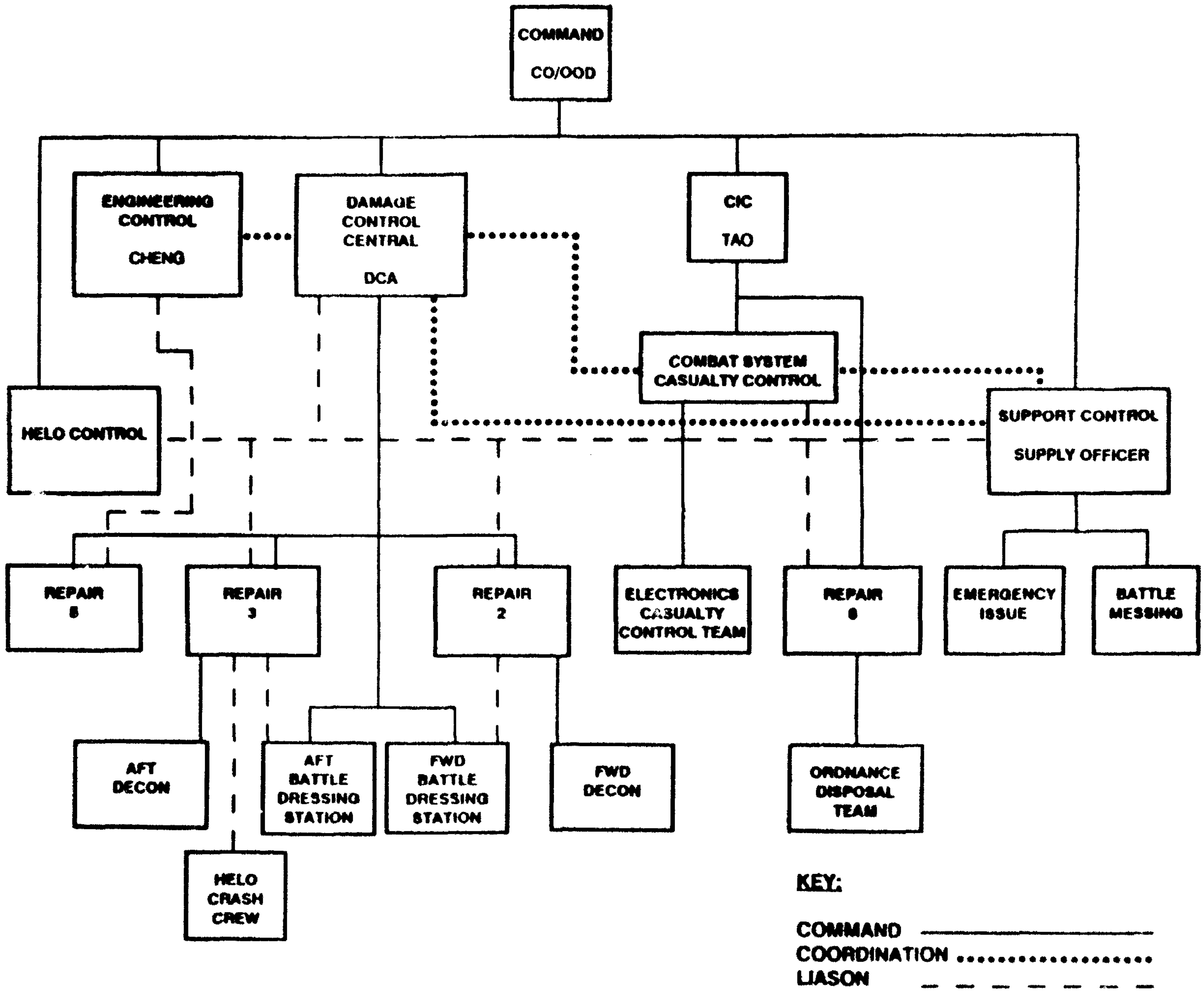


Figure 9 TYPICAL CONDITION I DAMAGE CONTROL ORGANIZATION

hancements are put in place prior to the casualty. This is done in a graduated fashion relative to the threat by establishing "material conditions" representing increasing states of survivability. These material conditions are set at a minimum level for overhaul condition and at increasing levels as conditions warrant. This approach minimizes the impact of the survivability measures on access throughout the ship and on ship system operation. The basic conditions of readiness are:

X-RAY: Set for in-port operations. Valves to portions of vital systems, or closures in tight bulkheads to spaces which are infrequently used, are secured.

YOKE: Set for normal at sea conditions. Closures which result in moderate segregation (which facilitate the setting of ZEBRA without totally restricting access or flow), valves to portions of vital systems, and closures in tight bulkheads to spaces which have moderate use are secured.

ZEBRA: Set for battle conditions. Closures that result in full segregation, shut off non-vital portions of vital systems, or secure open piping paths are secured.

CIRCLE WILLIAM: Set for CBR-Defense. Vent valves that prevent the flow of outside air into the ship are secured. Vent supply and exhaust fans are secured.

Floodable volume is divided into smaller subdivisions to prevent loss of the entire ship's buoyancy with a single case of damage. The main transverse watertight bulkheads provide this protection; however, they include access and ventilation openings. The bulkheads are made tight by securing watertight access closures and ventilation closures. These closures are classified ZEBRA, because they will only be shut during battle quarters, allowing easy access during other conditions.

Critical systems are divided into segments to provide graceful degradation when damaged. Valves are closed, circuit breakers are opened, and pumps, generators, compressors and other equipment are energized as required by the current material condition. Systems are segmented into two or more subsystems as the threat increases, each subsystem with a source, a distribution system and users; thus when one segment is damaged, the entire system will not fail.

Exposure of systems to potential damage is minimized by isolating nonvital portions. Closing the root valve or circuit breaker of nonvital branches of systems eliminates the possibility that damage to that branch will cause loss of system pressure or voltage, thus minimizing the exposure of the more vital portions of the system to weapon damage.

Personnel and vital equipment are protected by utilizing the concept of "vital spaces". These spaces are surrounded by watertight or airtight structure, and protection is provided by closing watertight and airtight doors, hatches and ventilation closures to prevent water and toxic and explosive gases from entering the spaces. Doors which are used infrequently are closed in condition X-RAY. Doors which are used frequently are closed only in condition ZEBRA in order to cause least disruption to traffic during periods in which the threat is not present.

Quantities of required flammables and combustibles aboard are minimized. Inspections are routinely performed, and all unnecessary combustibles are discarded. This includes unauthorized flammable liquids, wood, cardboard and unnecessary paper in file cabinets.

Hazards are separated wherever possible (ie., flammable liquids are separated from explosives, and fuel and combustibles are not located near sources of sparks or flame).

Active countermeasure systems are maintained. These include all systems dedicated to the damage control function including firefighting systems and collective protection systems. Since these systems can be damaged even under normal, routine use, visual inspections and PMS of CPS boundaries, boundary and airlock doors, ventilation fans and filters, and active fire protection systems are conducted.

Passive protective boundaries (watertight, airtight and fumetight) are maintained. These boundaries are used to contain hazards due to weapons effects loadings that are too powerful to be controlled by active systems. The passive boundary concept is the most reliable approach to preventing spread of hazards due to weapons effects. Passive boundary take protection can take effect immediately when exposed to the hazard. Maintenance of airtight and watertight boundaries is accomplished by performing periodic, routine air tests and visual inspections. Maintenance of passive fire boundaries is accomplished by performing visual inspections.

Maintenance is routinely performed on vital systems, including systems that support damage control functions; i.e., the firemain and drainage systems as well as systems which support only the combat systems. These latter systems need to be maintained so that the damage control fittings can be operated as necessary to segregate systems or isolate damaged portions. Maintenance is also routinely performed on damage control equipment. Equipment is properly stowed, batteries are sufficiently charged, fire extinguishers are filled.

CBR Defense doctrine incorporates the concept of Mission Oriented Protective Posture (MOPP). Four MOPP levels provide for ship and personnel readiness conditions and individual protection levels responsive to the threat conditions and probability of attack. Actions associated with the MOPP system include breakout of equipment, operational inspections and tests, activation of the washdown system, activation of decontamination stations and contamination control areas, and closure of CIRCLE WILLIAM fittings. Individual protection levels associated with MOPP consider the fact that at times a "mask only" posture is adequate, whereas full body protection may be required at other times.

Repetitive training drills are emphasized. Both individual and team shipboard and schoolhouse training is routinely accomplished. Training drills are as realistic as possible, and cover all expected casualties within practicality (including the major conflagration drill).

When damage does finally occur, the critical functions become DETECTION, ASSESSMENT and ACTION.

DETECTION

The presence, nature and extent of casualty is identified as quickly as possible. This is accomplished by on scene personnel, investigators or sensors. Casualties include:

Fire: Fire is identified by the presence of smoke, visual identification of flames or by touching a hot bulkhead. Sensors react to ultraviolet radiation of a flame, the presence of smoke, the exceeding of a set temperature level or of a temperature rate of rise.

Flooding: Flooding is identified by personnel by visual observation. Sensors react to the exceeding of a set level of flooding. This is typically set at a few inches below the lower deck plate level. The cause for the high bilges must be established by investigation before damage control action is taken.

Loss of stability or buoyancy: The degree of stability or buoyancy loss is determined by the attitude of the ship, the known extent of the flooding, or by a logy ship rolling characteristic. The presence of flooding in the superstructure due to firefighting action, or the flooding of the compartments indicated in the DC Book to result in critical flooding is cause to take action to improve stability or buoyancy.

Damage to piping, IC or electrical system: Damage is indicated by visual observation of investigators or by loss of pressure in piping systems, loss of voltage in an electrical systems, and loss of communications in an IC system.

Smoke: The presence of smoke is indicated visually or by a smoke sensor.

Damage to boundaries: This is indicated visually observing the damage or by observing the progressive smoke spread or flooding which might occur as a result of the damage.

Presence of CBR contaminants: The presence of contamination is indicated by remote and point detection equipment. Spread of CBR contaminants may be indicated by portable detection and monitoring equipment, and by visual observation of the effect on personnel or by the indications of portable sensors. If a ship has been exposed to a successful chemical or biological attack (i.e., chemical or biological agents are inside or on the ship), or it has been contaminated with radiological particulate, it must be perceived as having taken a hit and sustained damage, even though it may be structurally intact.

Toxic gas: Spread of toxic gas may be indicated by the visual observation of the effect on personnel or by the indications of portable sensors.

Compromising of gun, ordnance, missile or magazine spaces: Potential damage to these spaces is indicated by visual observation of spreading fire or flooding in the vicinity of the spaces or by the high temperature alarms.

Structural failure: Damage to structure is indicated by visual observation.

Personnel injury: Injury to personnel is indicated by visual observation and/or communication.

ASSESSMENT

Timeliness is critical. Most casualties accelerate in intensity and must be stopped in the early stages. This requires constant patrolling by the sounding and security patrol (when not at general quarters) or the investigators (at general quarters). It also requires quick thinking by the Damage Control Petty Officer of the Watch (DCPOOW), the Repair Locker Leader or Damage Control Assistant in recognizing hazardous situations and organizing the appropriate response. The basic steps to support assessment include:

Receiving input concerning presence, location, type and extent of casualty.

Displaying/presenting casualty input information.

Appraising the casualty, and determining the course of action. This may involve conflicting recommendations. For example, multiple threats and weapons effects (e.g., CBR combined with fire and flooding) can lead to incompatible damage control/ personnel protection recommendations. When faced with conflicting alternatives, prosecution of the most serious hazard takes precedence, and will be a local command decision based upon specific scenarios.

ACTION

Efficient response to the casualty is the primary goal. Once the presence, type, location and extent of the casualty are determined by sensors and by investigators, shipboard alarm and voice communication circuits are used to relay this data to the damage control repair stations and to DC Central. At both stations the information is plotted manually on damage control diagrams. Figure (10) shows a typical DC diagram. This display supports analysis, determination of possible courses of action, decision making and tracking of progress. The selected course of action is implemented by voice command and by remote control where provided. The response is expected to follow established procedures:

- Direct the response to the casualty.
- Monitor the casualty progress.
- Coordinate with other ship departments.
- Coordinate actions among casualties.
- Control the resources.
- Maintain information flow to Command center.
- Provide recommendations to Command.
- Provide continuous updates to Command

Coordinated action is initiated by communicating presence, location, nature and extent of casualty to central location. This may be accomplished by sensors; however, most information is assimilated and transmitted by investigators. Typical actions are:

- Establishing primary and secondary fire and flooding boundaries. The primary boundaries are the closest watertight, airtight or fumetight boundaries to the fire or the closest watertight boundaries to the flooding source.
- Activating water washdown against CBR threat. This system prevents the contaminants from reaching and contaminating the skin of the ship. This minimizes the need to decontaminate post attack.
- Utilizing CPS boundaries. The CPS pressurization concept results in an outflow of air from any openings in the CPS envelope, keeping contaminants outside that envelope. Inlet air is filtered to prevent the entry of contaminants.
- Donning protective clothing appropriate for the expected/ actual damage control environment.
- Reporting to central control actions taken against the casualty, changes in the nature or extent of the casualty and requests for assistance. The DCA tracks the reports, coordinates actions, and provides resources as required.
- Taking extended action to alleviate casualty, in support of immediate efforts already begun.
- Repairing or minimizing breaches in passive boundaries.
- Isolating damaged portions of systems, and reenergizing remaining portions using surviving valves and crossconnections. Flow at the valve nearest to the damage is secured. Valves in cross-over piping (used to reconfigure the system) are opened, thus bypassing the damaged piping. Once the damage has been isolated and the system reconfigured, the valve necessary to cross connect with the neighboring energized portion of the system is opened.
- Reenergizing remaining portions of systems using jumpers. Where a system is not designed for reconfiguration, or where a vital branch is between the damage and the nearest isolation valve, a jumper is required. Jumpers are possible on the fire main between fire plugs.
- Desmoking. After the fire is extinguished, desmoking of the space is accomplished via installed ventilation or portable exhaust fans. The smoke is exhausted from the spaces, and is directed to the weather using installed or portable ducting to prevent spread of explosive and/or toxic gas to other parts of the ship.
- Conducting gasfree operations. The success of the desmoking effort is determined by testing the atmosphere in the space for explosive gas, oxygen and carbon monoxide. Where is suspected that PVC has been burning, additional tests are required.

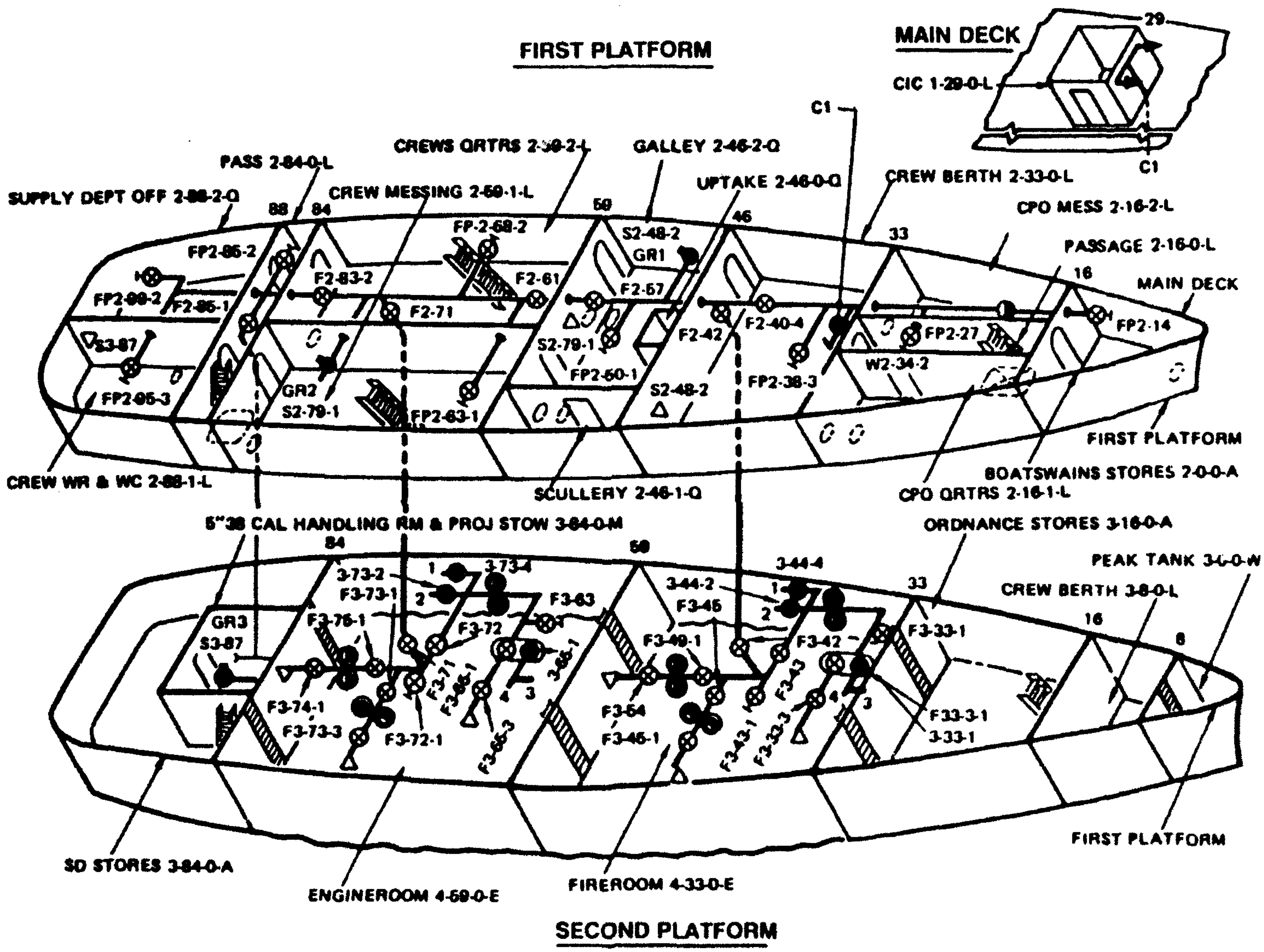


Figure 10 TYPICAL DAMAGE CONTROL DIAGRAM

- Overhauling the remains from the fire. In order to ensure all burning embers have been extinguished, the remains from the fire is overhauled by raking through the debris, and spraying water on the embers.

- Setting the Reflash Watch. Personnel are required to maintain watch over the spaces affected by the fire, to extinguish any reflashes.

- Dewatering the affected spaces. Once flooding has been stopped, flooded spaces are dewatered. Dewatering of firefighting water commences when stability is threatened; however, a Command decision may reprioritize this doctrine depending upon specific damage scenarios.

- Shoring damaged vital structure. Shoring is used to support damaged watertight bulkheads or hull plating against water pressure in order to prevent or minimize flooding. Shoring is also used to support damaged decking underneath vital equipment and to support decks or bulkheads which have been distorted by blast pressure. Figure (11) illustrates typical DC shoring schemes.

- Repairing damaged vital piping. Piping which has not been completely severed can be patched using authorized pipe patching kits.

- Decontaminating ship and systems from CBR effects. A command decision will set priorities based upon specific scenarios. The possibility of having to perform mission tasks in a contaminated environment highlights the need for on-scene risk management, and the importance of information. For a commander to weigh the risks of casualties against lost time for decontamination, or the performance degradation due to personnel protection equipment, he must have the right information, much of which must be provided by the technical community. This technical guidance is as important to mission success as CBR-D material, and efforts to develop or refine this guidance for the Fleet ranks very high in the NAVSEA CBR-D priorities. Just as a ship cannot always fully recover from damage after a conventional attack, it will not always be practical or feasible for the crew to fully restore a contaminated ship without industrial assistance or, in the case of agent weathering, relying on natural events; i.e., total ship decontamination by the crew to risk-free levels is technically impracticable and logistically insupportable.

- Performing first aid/transporting casualties. Use equipment provided to perform first aid. Transport personnel to battle dressing stations in stretchers.

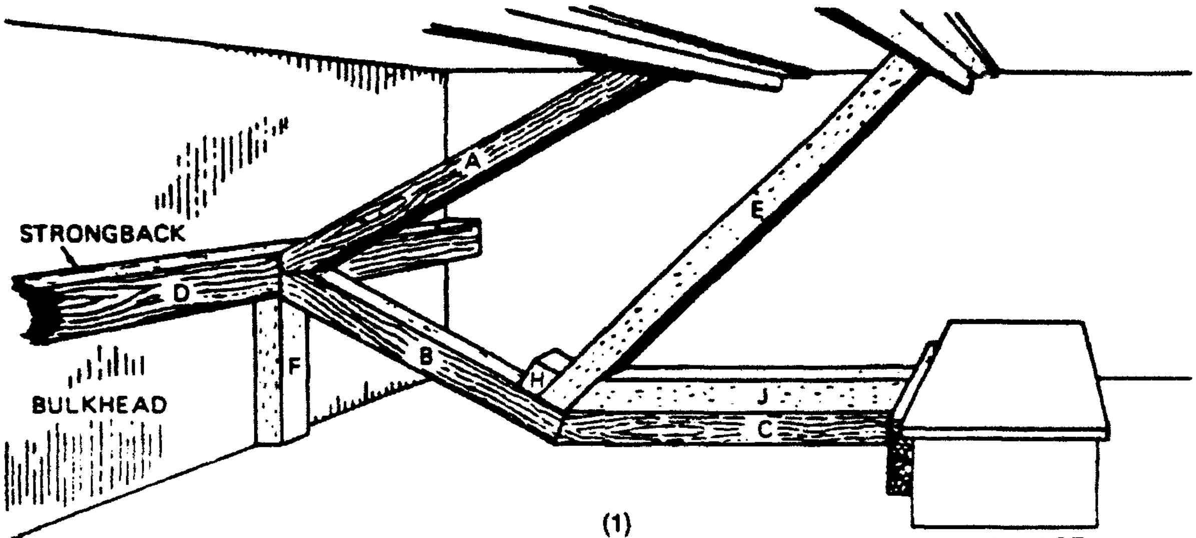
- Using available technical documentation. The damage control book and diagrams are provided to support operations and training. The book describes key systems and provides diagrams depicting the ships arrangements and systems. The book also contains information essential to preserving stability and buoyancy. The ship is also provided with general damage control information in the Naval Ship's Technical Manual. General shipboard DC training requirements are found in the Personal Qualification System (PQS) manuals.

TRAINING

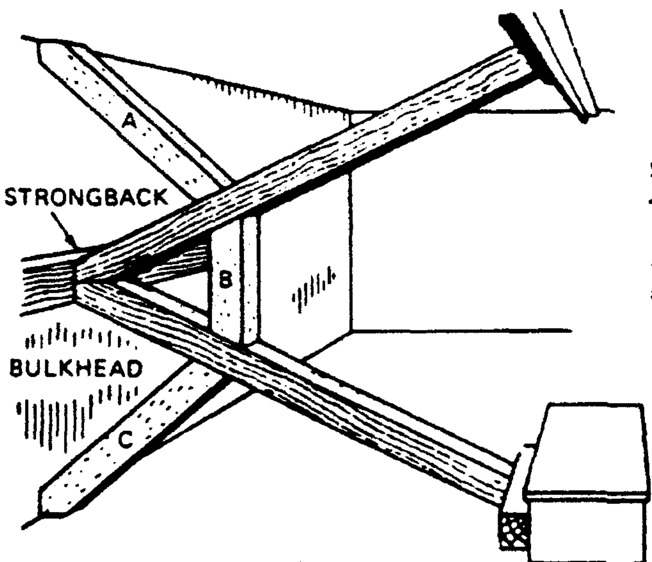
Training is required to prepare the crew to conduct damage control, and to reinforce those skills already learned. All ship's personnel receive DC training. Information on updated equipment and procedures are also an important part of the training programs. The proper use of equipment and systems are taught to all who will be involved with the DC process. Training is conducted by the fleet both aboard ship and ashore, is conducted on actual shipboard-representative equipment or on special training equipment. The training scenarios are as realistic as possible. Although shipboard training is preferred, shore based training is used when realistic fire and flooding environments cannot be simulated aboard ship. DC training is a never ending series of skills reinforcement, resulting, ideally, in a capability of the sailor to instinctly and immediately react to all types of expected casualties. Key elements of the Navy DC training program include:

Training plans: Training plans are developed for individual systems and equipment developed through the acquisition process, and are initiated during ship design. Ship-class unique training requirements are included in the ship training plan. The Damage Control Navy Training Plan is updated annually.

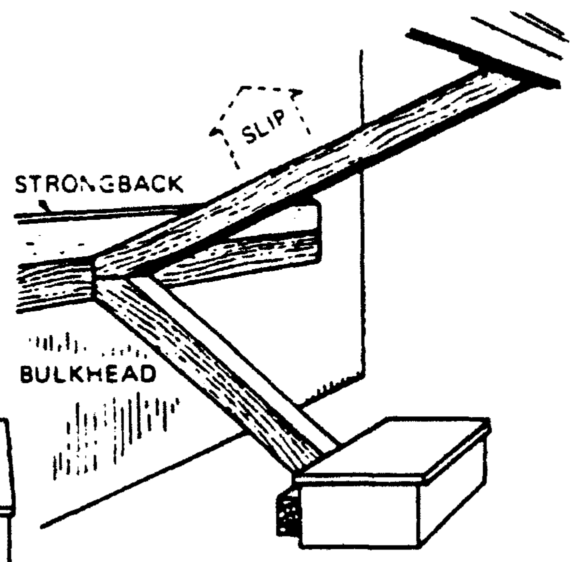
Shipboard training: To insure familiarity with on board equipment, training is conducted on the installed equipment (except for the breathing devices where training OBAs and EEBDs are provided to reduce the expense of expending actual canisters or devices). Realistic simulation of all weapon effects aboard ship would be destructive; therefore, simulation techniques are used as necessary. Typical simulations would include blindfolding of personnel or shutting off lights to create darkness, and the usage of smoke generators to simulate actual smoke. Training procedures are developed by the fleet to improve on skills initially provided by shore based training. Most training scenarios are traditional, however computer developed scenarios are being developed to realistically involve all ship systems. The Naval Ships Technical Manual (NSTM) provides ap-



(1)
THE STRENGTH MEMBERS HERE - A, B, C, D, HAVE BEEN LOCKED IN PLACE WITH AUXILIARY SHORES E AND F TO KEEP THEM FROM JUMPING OUT AS THE SHIP WORKS. CLEATS H AND J HOLD E IN PLACE.



(2)
RELATIVELY LONG SHORES WHICH SUPPORT HEAVY PRESSURE, MAY HAVE A TENDENCY TO BOW. SUPPORTING SHORES A, B, C, SHOULD BE INSTALLED FOR GREATER STRENGTH.



(3)
WHEN ONE SHORE IS LONGER THAN THE OTHER, A WIDER STRONGBACK WILL KEEP THE LONGER ONE FROM SLIPPING.

Figure 11 STRENGTHENING SHORES

propriate documentation to support training. Personnel Qualification Standards (PQS) are developed by the fleet from basic damage control documentation.

Embedded training: Embedded training is included with damage control computer software. The embedded training module presents the crew with a problem exactly as it would appear on the computer monitor, improving the realism of the training experience.

Shore based training: DC trainers are provided to improve the realism of shore based training. Trainers have been built to teach firefighting, desmoking, pipe repair, shoring, flooding control and decontamination procedures. Simulants are available for chemical defense training. Training equipment is provided to all training commands to support above procedures. Training procedures and curriculum guides, developed by the training commands, are based on the DC Books and technical manuals. Training audits are conducted to ascertain that the proper training equipment is available and that doctrine being instructed reflects current technical procedures.

FUTURE TRENDS

It is apparent that one of the more significant issues facing the Navy of the future is planned reductions in shipboard manning levels. Since the conduct of effective shipboard damage control, as we know it today, is so highly dependent upon sufficient numbers of personnel, the basic concepts and traditions of this discipline must be changed in order to accommodate this pending reduction. While an intrinsic knowledge and proficiency in DC skills will continue to be a basic requirement of every sailor, modern decision aids and automated responses must be developed in order to insure that the DC process can cope with modern threats. Also, ship design improvements and updated damage control techniques affect, and are affected, by each other. Improvements in one will, and should, result in improvements in the other. Finally, the concept of "fighting hurt" will be pushed even harder, as damage control/vital system restoration response time becomes more critical, given the new generation of smarter weapons and more efficient delivery systems. Automated decision making aids, and responses will form a significant part of the DC process. Looking into the not too distant future we see:

Integrated Survivability Management System (ISMS)

Ships of the future will feature the Integrated Survivability Management System. Computer driven consoles in each repair station and in DC Central will collect, analyze and display data, and will support remote control of key closures. By significantly reducing DC response time, the payoff will be reduced ship system downtime, enhanced combat readiness and warfighting sustainability, and reduced repair costs. Figure (12) illustrates the concept of an ISMS installation on a modern destroyer.

All communication will be handled by the ship's redundant, survivable data network. Temperature, smoke, chemical, toxic gas, liquid level and closure position sensors will transmit data to the DC consoles, graphically displaying the data. These human engineered displays will immediately communicate to the DC personnel the nature and extent of the casualty. The consoles will have the ability to analyze the data and present alternative courses of action, based on current DC doctrine, to the DC personnel. The DC personnel will decide on the appropriate course of action and carry it out by both voice command and remote control. Figures (13) and (14) illustrate candidate displays currently under evaluation.

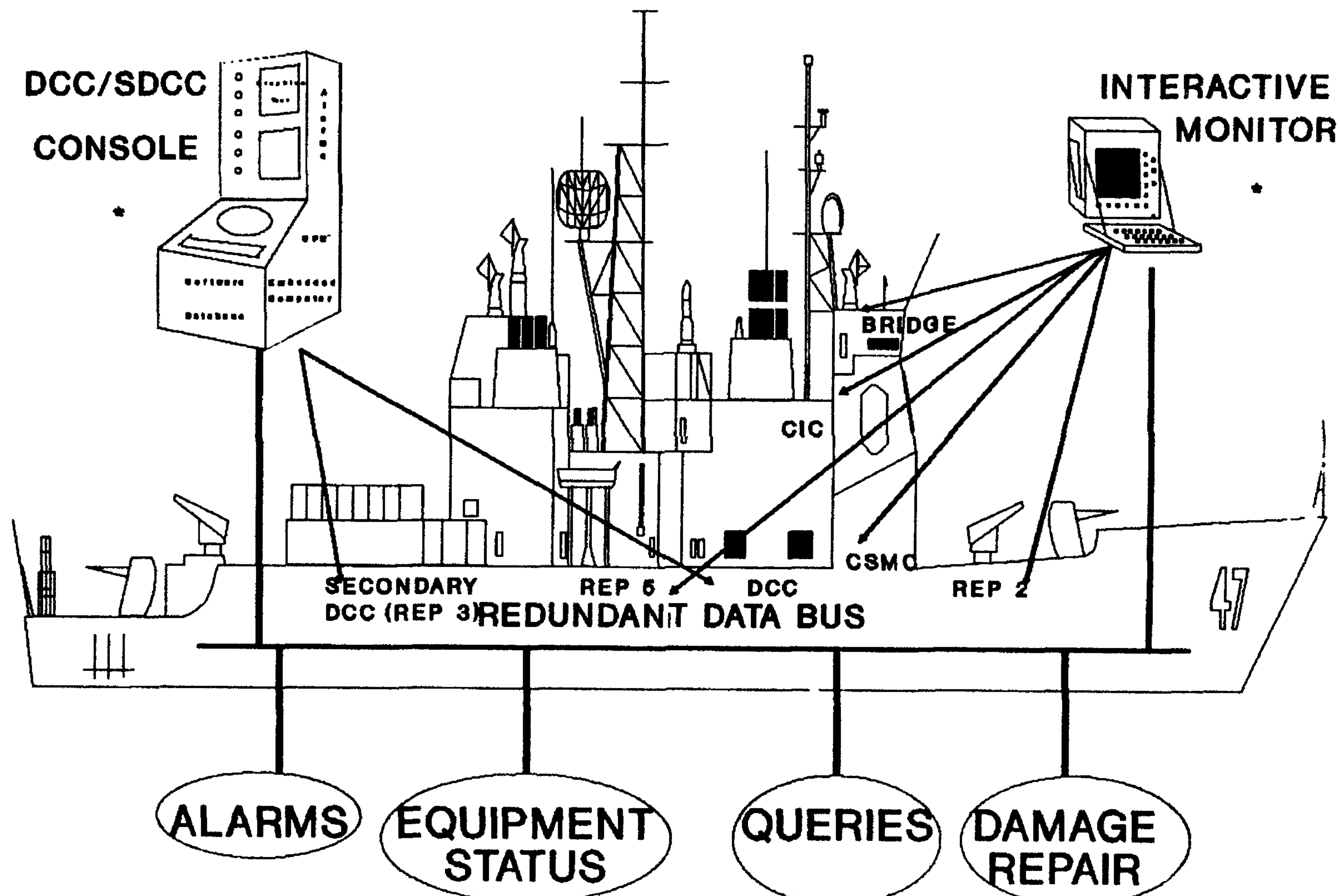
One of the modules, the Flooding Casualty Control System (FCCS), is currently under evaluation aboard selected ships. FCCS uses manual input to calculate stability and then analyze the results to determine the degradation in stability performance. FCCS uses both tabular and graphical displays for input and output. Ultimately, FCCS, and similar systems will be fully incorporated into ISMS, thus affording true artificial intelligence capability to augment crew expertise.

ISMS will blaze new trails in DC training. Both schoolhouse and shipboard DC training will benefit from the realistic and very cost/time effective scenarios that can be simulated on ISMS.

Upgraded DC Equipment

The trend in portable equipment is to pack more capability into smaller packages. The new desmoking blower currently in process of delivery to ships has more than three times the capacity, and is significantly smaller and lighter, than the existing blower. A new portable exothermic cutting torch unit (PECU) can cut materials and thicknesses impossible with the old oxy-acetylene torch. New portable hydraulic access and rescue equipment (PHARS) affords DC personnel the capability of gaining access for repair and personnel rescue by applying thousands of pounds of force for cutting or spreading ship structure. This rescue equipment will provide the

ISMS CONCEPT



* To be developed

FIG 12

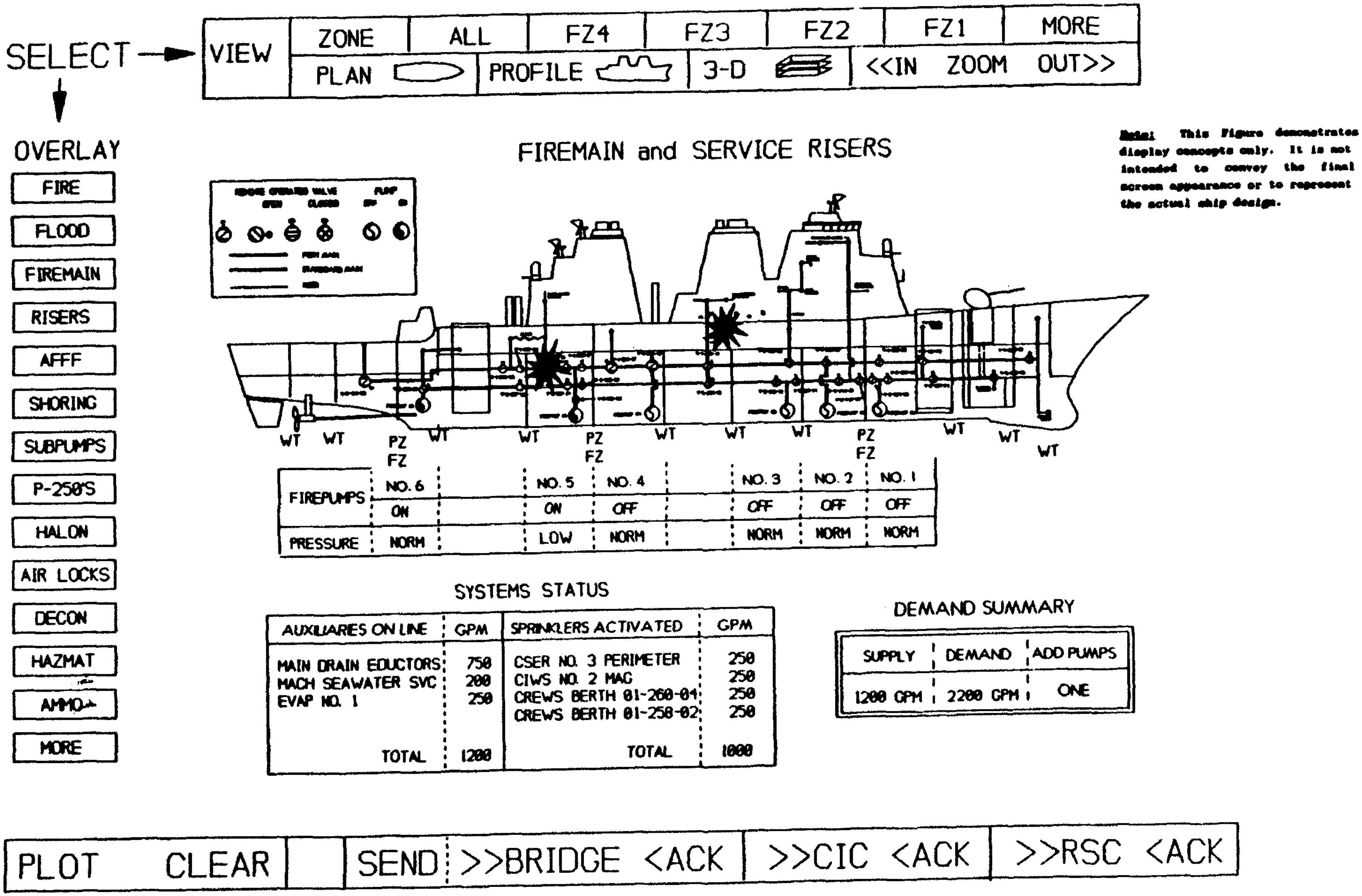
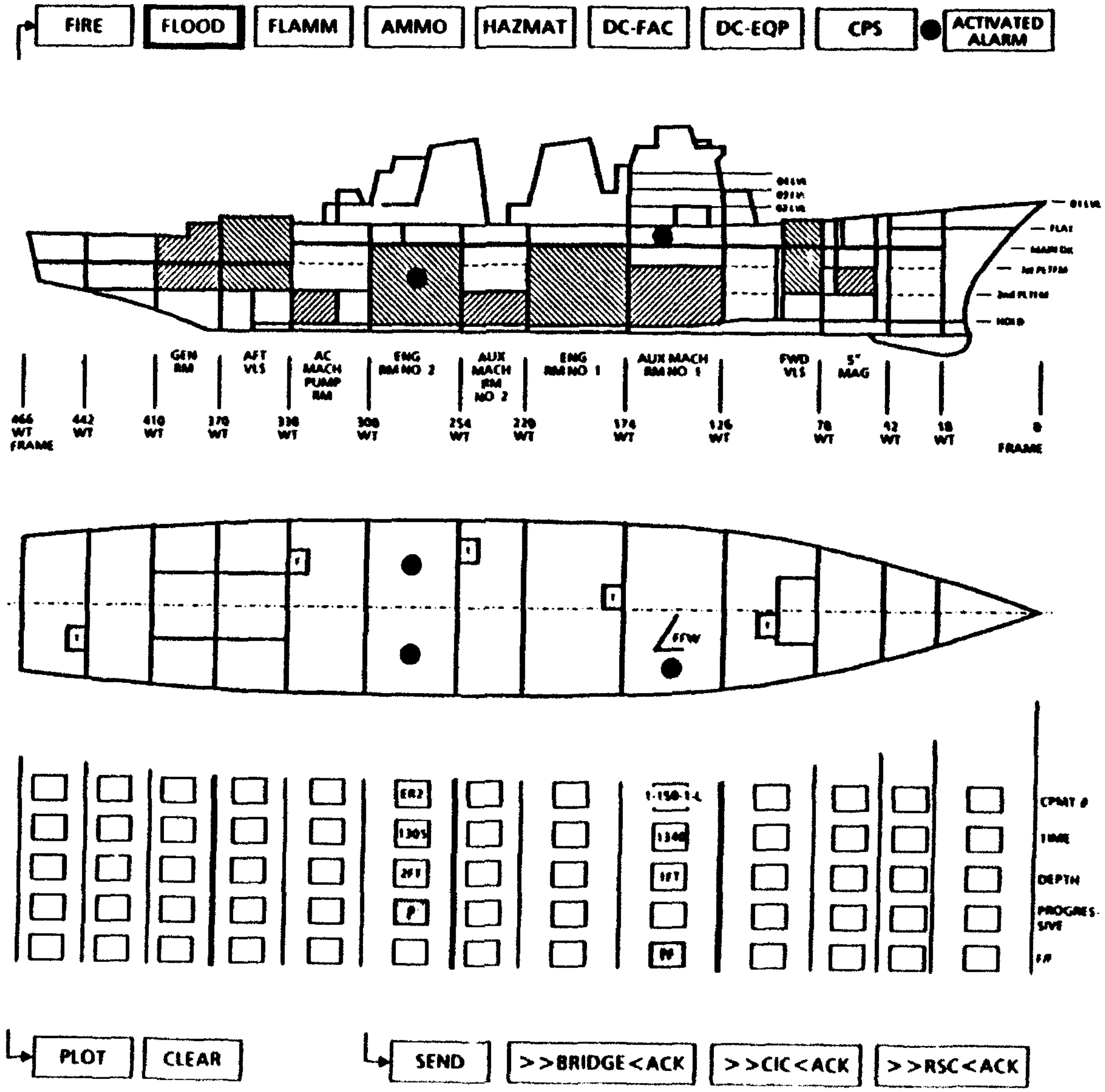


Figure 13 EXAMPLE OF FULL GRAPHIC DISPLAY - CONCEPTIONAL

APPROXIMATES VIEWING
AREA OF 8" PLASMA DISPLAY



Note: This Figure demonstrates display concepts only. It is not intended to convey the final screen appearance or to represent the actual ship design.

Figure 14 EXAMPLE OF BASIC DISPLAY - FLOODING

capability to cut through metal bulkheads without using flame. A new firefighting/dewatering pump is under development which can lift water over the high freeboards of today's ships. The wirefree communications system (WIFCOM), currently under installation on ships provides damage control communications via radio, using a leaky coaxial antenna to transmit through the metal bulkheads. This system solves the problem of conducting timely communications when the IC cables have been damaged.

Upgraded Personnel Protection Equipment

The emphasis is on increased capability with improved comfort, while stressing the concept of multifunctionality. Under development are (1) The Special Applications Firefighter's Helmet, which combines thermal imaging, head and eye protection, communication and emergency lighting, and (2) The firefighter's breathing apparatus (FFBA) that affords firefighters with a positive pressure air supply in a compact, backpacked unit, thus replacing the WWII-design oxygen breathing apparatus (OBA).

Improvements in CBR Defense equipment will consider future threats, and will emphasize protection with minimum personnel performance degradation.

Improved Ship Designs

When a combatant ship of the future is hit with a weapon, damage should be minimized because of design criteria to mitigate such damage. The keel can be strengthened to provide more protection against underwater shock. Internal arrangements can incorporate the placement of armor and/or other barriers around critical spaces to protect against enemy weapons. Internal arrangements of equipment can employ more separation, and more redundant paths for electrical and electronic system's power and information.

CBR Defense systems will include improvements in collective protection and features to assist in control of topside contamination, such as improved coatings and ship design features that enhance water/agent runoff.

The concept of enclaving vital sections of the ship will result in enhanced damage control. Ships can be designed with autonomous, or at least semiautonomous, regions which, containing a subset of ship's mission capability, could continue to provide that capability even if one or perhaps two regions were damaged due to a weapon hit. The higher probability for survivability of undamaged ship sections will afford the maximum capability of restoring damaged portions, and will minimize the effects of damage on ship mission capability. Figure (15) illustrates the enclaving concept.

ACKNOWLEDGEMENTS

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CONCLUSIONS

This paper has attempted to acquaint the reader with the subject of shipboard damage control, as currently practiced by the U.S. Navy. As discussed herein, we have seen that damage control involves the ship and equipment designers, the fleet users and the training establishment. Also, as we can surmise, NAVSEA plays an extremely important role in all aspects of the subject, especially in the ship and equipment design phases. We have come a long way in a relatively short time; however, we have nearly maximized the payoffs from current philosophy. We must now think "revolutionary" vice "evolutionary" concepts for damage control. ISMS is a start; novel ship designs will also drive the discipline forward. Continuous interface with the fleet will remain a vital component in ascertaining future needs. With more emphasis being placed on survivability, one can be sure that "damage control" will remain a very high priority in the overall NAVSEA effort to build better ships for the fleet.

REFERENCES

[1] Naval Ship's Technical Manual, NAVSEA S9086-CN-STM-020, Chapter 079 Volume 2, Practical Damage Control.

[2] Shipboard Protective Clothing Catalog, August 1987, US Navy Clothing and Textile Research Facility.

[3] Surface Ship Survivability, Naval Warfare Publication NWP 62-1 (Rev. C).

[4] Report of the Ship Operational Characteristics Study on the Operational Characteristics of the Surface Combatant of the Year 2010, OP-03K, dtd 26 April 1988

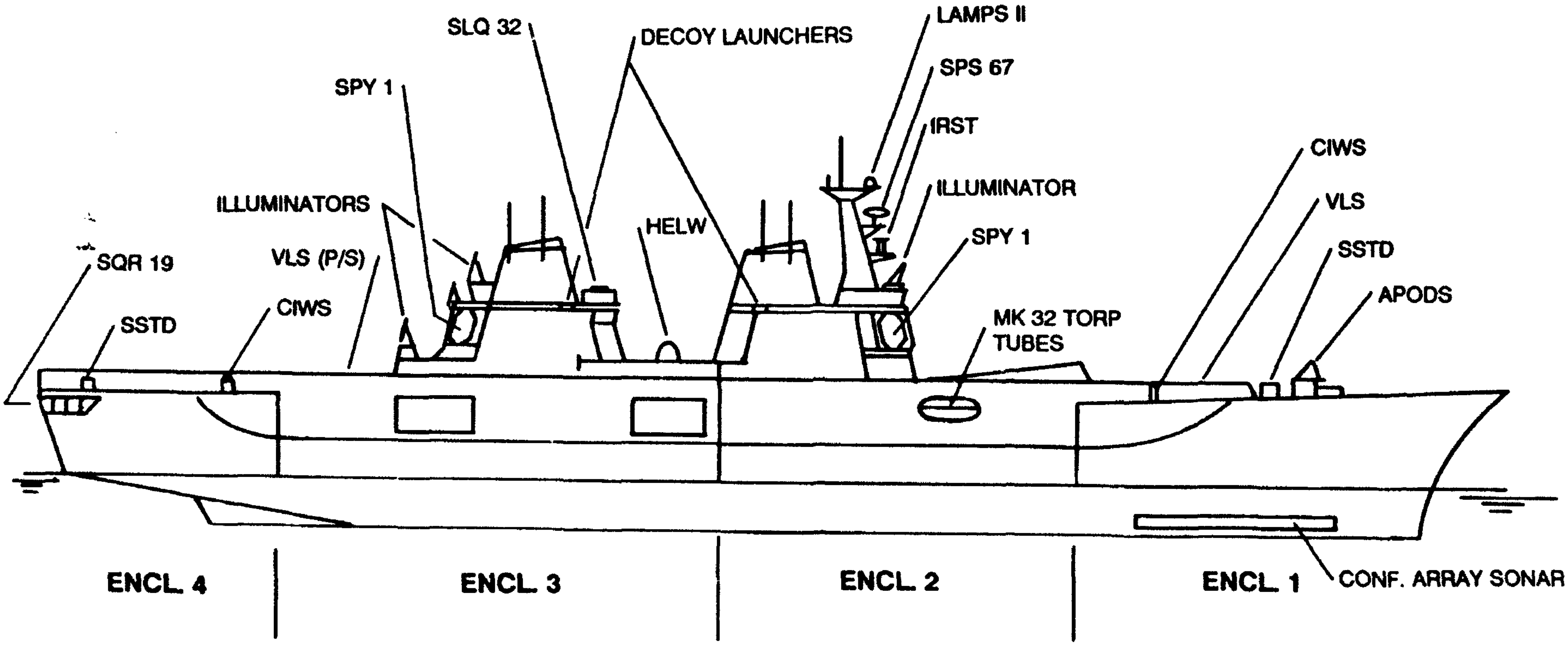

Figure 15 ENCLAVED LOCATION OF EXTERIOR COMBAT EQUIPMENT

PROBABILISTIC SHIP STRUCTURAL DESIGN

Robert A. Sielski
Structural Integrity Subgroup
(NAVSEA 55YP1)
Naval Sea Systems Command

April, 1991

Approved for Public Release
Distribution Unlimited

ABSTRACT

Adoption of probabilistic methods for the design of ship structures entails a change in the thought process that leads to specifying ship structural strength and maintenance requirements. For conventional ships, current requirements are based on the experience of developing many ship designs and on vast operational experience related to the performance of and maintenance on those ships. Any significant change in the ship performance envelope, ship configuration, hull structural configuration or hull materials entails extrapolation of this experience. Such an extrapolation is inherently risky and may lead to costly structural damage or maintenance problems. Probabilistic structural design methods offer the best alternative to the costly traditional trial and error approach as a means for evolving requirements for ship structure and design criteria. However, these methods require the acquisition and processing of a vast amount of data related to ship's operational environment, structural loads and the ship structure's resistance to these loads. An extensive five year R&D program is planned to provide better definition of loads, strength of structure, and to develop the appropriate means of implementing structural reliability in the design of ship structures.

LIST OF FIGURES

INTRODUCTION

Inherent in the probabilistic approach is the notion of acceptable risk of structural failure. Accepting this notion is part of the cultural change that must occur before reliability based design can be implemented, because the designer and the those who specify the structural requirements must negotiate with the customer to define acceptable probability of failure levels compared to the costs associated with reducing the probability of failure. An essential part of this process is the determination of risk, which is the product of probability of failure and some measurement of the consequences of failure. As quantification of the consequences of structural failure can be difficult, subjective judgement is generally necessary for risk assessment. For both parties these considerations require a rigorous statistical assessment of a large amount of information, and are difficult decisions to make. In a recent study of cracking of a non-critical area of the structure in a class of ships, the "customer" initially accepted a reduction of the probability of crack initiation from 90 percent in 10 years to 30 percent in 30 years as a practical compromise considering both the cost of structural modifications and the limited consequences of failure. However, as the reality that this level of probability meant that some cracking would continue, a more expensive modification was invoked that changed the probability of initiation to five percent in 200 years. The "customer" must also be more explicit with regards to specifying ship performance environment (speed, heading, sea states), exposure time to this environment, as well as well as required lifetime of the ship. All these factors affect ship structural loads and hull structure design.

For the designer, probabilistic design requires a total rethinking of the design and construction process, from loads to materials and fabrication. For wave loads, whose only rational description is probabilistic, the task is easy. Indeed, probabilistic design is the natural consequence of the statistical nature of the sea environment. Other deterministic loads, such as static deck loads, have been standardized historically, and require more investigations to determine their true nature, and to describe them statistically. The influence of factors such as accuracy of structural alignment, and fabrication effects and their degradation of the resistance factor must be accounted for, so we may find that shipbuilding practices may have to change to accommodate the advantages of probabilistic design.

STRUCTURAL DESIGN EVOLUTION

Structural design of ships has evolved over many years through extrapolation from past practice. The problem is that of addressing the triad of design load, design method and design allowable stress in a consistent manner so as to obtain satisfactory ship structure. Historically, one or more of these factors have been changed at various times to address current needs. In the late 1940's, there was unsatisfactory service experience with some combatant ships, especially with some cruisers, on which the foredeck plating buckled in heavy seas, and eventually led to the loss of the bow on one ship. To increase the ruggedness of ship structures, the design primary stress was increased to the current 8.5 tons per square inch (tsi) for HTS. While this change was made to the design stress, the method of calculation, hydrostatic balance on hogging and sagging waves, and the design load of wave height equal to $1.1\sqrt{LBP}$ remained unchanged from past practice. When sponsons on aircraft carriers began to suffer damage, the design load was increased to as high as 7200 pounds per square foot, but the allowable working stress remained the same. In the early 1970's, as finite element analysis methods became available, they were used for design of structure, particularly for grillages and transverse frames, but with no change in design loads or allowable stress.

When a new material, aluminum, was introduced as the primary hull material, no precedent for ship design existed. Concern for the possibility of excess deflection because of the reduced elastic modulus led to a design procedure to give stiffness equivalent to a steel hull. A steel hull was designed first, and then an aluminum hull was designed having three times the moment of inertia midships as the equivalent steel hull. This hull had a bending stress of 3.5 tsi when statically balanced on a $\sqrt{1.1}$ LBP wave, so that became the design standard for aluminum ships. Because of satisfactory service experience with aluminum hulled ships, that initial conservatism has been relaxed and the most recent aluminum ship was designed to 4.5 tsi.

As design of unconventional ship types began, the ability to fall back on past practice was lost. In the design of hydrofoils in the late 1960's and early 1970's, service experience similar to other ships was desired, but traditional methods of analysis were not applicable. The design method was then based upon static moments when supported on the foils, with 4.5 tsi used as the design allowable primary stress for aluminum. Design of surface effect ships presented a greater problem. Tank model tests in waves showed that the greatest longitudinal bending moments could come from slamming when the ship was hull borne in head seas. No analytic method was available to replicate this condition, so the design had to depend upon model tests. Testing opened two sources of load variation. The maximum slam load is a function of relative heading to the waves, the wave height and frequency, as well as the speed of the ship. Any model testing is subject to experimental error, so an identical response is not always measured in the same conditions. To account for this variability, probabilistic techniques were used to predict the maximum lifetime slam load. Reliability analysis determined that the load had a probability of exceedance of three percent. This load was then applied to a finite element analysis, with conventional design allowable stresses used.

Design of Small Waterplane Area Twin Hull (SWATH) ships presented a similar problem, in that the primary load, transverse bending, could only be determined experimentally. In this case, a standardized method of determination of the maximum lifetime transverse bending moment was developed. This method was then applied to a series of conventional ships, finding that it produced a longitudinal bending moment 50 percent greater than the standard $1.1\sqrt{LBP}$ wave. Accordingly, the maximum moment predicted by this Dinsenbacher-Sikora [1] method was reduced by 0.67 for the design moment to be used with the standard design allowable stress.

All of the above examples represent attempts to change design procedures to accommodate changing needs. The underlying theme is a desire to have service experience as good as past ships have had. Quantification of the meaning of "satisfactory" was not made, only the assumption that past design practice had produced good ships, or had been appropriately modified after the discovery of problems.

STRUCTURAL RELIABILITY

Structural reliability is defined as the probability that the load imposed upon a structure does not exceed the resistance of that structure to that load. This is shown schematically in figure (1), where the probability density function $f_Z(z)$ of the load Z and the probability density function $f_S(s)$ of the resistance S are shown together. Failure is defined by a function $g(s,z)$, called the limit state function, which describes the safety margin M between the resistance and the load,

$$(1)\quad M = g(s,z) = S - Z\,.$$

Failure is represented then when M is less than zero, and, conversely, a safe state is represented when M is greater than zero, for then the resistance is greater than the load. The probability of failure can then be computed from

$$(2)\quad p_f = P[M = g(s,z) \le 0] = \iint_{g(s,z)\le 0} f_{s,z}\, ds\, dz$$

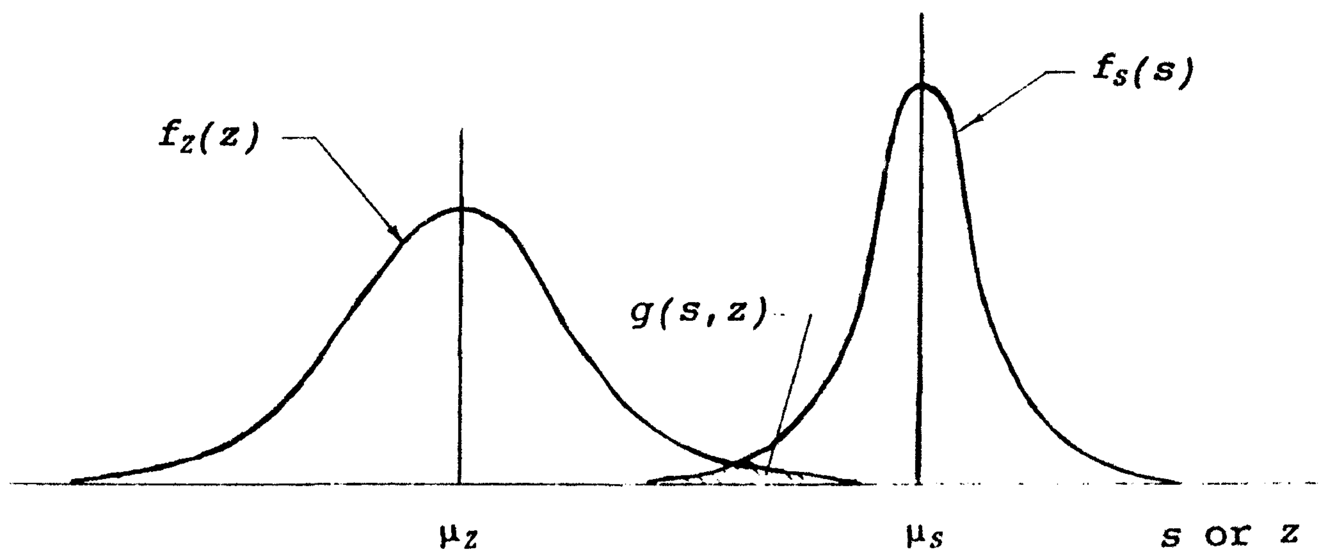

Figure 1 Probability Density Functions of Load And Resistance

where $f_{S,Z}(s,z)$ is the joint probability density function of S and Z, and the domain of integration is over all values of s and z where the margin M is not positive, that is, not in the safe state. In figure (1), the probability of failure is represented schematically by the area of overlap between the load and resistance probability density functions.

For the simple example of an axial tensile specimen in a testing machine, the load is the force produced by the machine, and the resistance is the product of the cross sectional area of the specimen and the ultimate strength of the material. In all cases, both load and resistance are random variables. For the simple example cited, many mechanical variances in the testing machine and instrumentation errors will make the true load different from the value desired or indicated. The resistance will be a random variable because the strength of a material is always different from the specified strength, and manufacturing errors will make the cross-sectional area different from the specified amount. Determination of structural reliability thus entails the determination of the probability density function of the loads and of the resistance, and integrating the joint probability density function of the limit state.

If all of the probability density functions can be represented by a standard probability distribution, such as the normal distribution, integration of equation (2) is straight forward. For complex structures, such as ship structures, neither the load nor the resistance are represented by single variables, but by many different variables. The limit state equation becomes a complex function of loads, geometry, materials, fabrication and other variables. The mathematical complexity is further increased by the fact that all of the variables posses different probability distributions. For example, the yield strength can generally be represented by the normal distribution, but properties of sections tend to follow a log-normal distribution. The distribution of loads is even more complex, with various distributions, including the Weibul distribution, used for extreme wave events.

Equation (2) is solved in four different ways, either by direct simulation, or by the use of Level I, Level II, or Level III approaches. The direct simulation, or Monte Carlo, method generates random values of all the variables in accordance with their probability density functions, and uses these values in the limit state equation to determine if the event being simulated is a failure or a safe event. This process must be repeated in order to obtain a estimate of the probability of failure, with several thousand simulation events generally required. The computations involved in this process require the use of a computer, but even then can be accomplished in a reasonable time only for the simpler cases.

Level III, or direct integration approaches solve equation (2) through methods of numerical integration, which also require large amounts of computer time. Implementation of Level III methods also requires the probability density function of all of the design variables, for which sufficient information may not be known to fully characterize the probability distribution.

Level II, or safety index approaches overcome the mathematical difficulties and lack of information by creating an equivalent normal distribution, where the random variables are characterized only by derived means and standard deviations. Several methods of derivation are used, but all represent an approximation to the actual reliability of the structure. However, Level II approaches are used extensively because of the decreased computation involved.

Level I, or partial safety factor methods are not true reliability methods, but are based on the use of structural reliability computations. The most common Level I method is the Load and Resistance Factor Design (LRFD) method. In this method, factors are determined for each variable associated with load and resistance. For instance, if some nominal load is used which is known to have an extreme value 50 percent greater than the nominal load, then a factor of 1.5 is used with that load. To compute the individual partial safety factors, a calibration procedure is used with existing designs, and iterations are made using assumed values of the partial safety factors until the desired level of reliability is achieved. The advantage of the LRFD method is that once the partial safety factors are determined, they can be specified in a design procedure, and the computations associated with design are not increased in complexity compared to the conventional approach, where a single factor of safety was inherent in the design process.

LOADS

For ships, the loads imposed take many forms, and they are imposed either simultaneously in some combination or independently from each other. Most important of all loads are wave loads, which are extremely variable in magnitude due to the nature of the sea. Associated with the wave loads are slam loads caused by the impact of the hull with the surface of the water during extreme ship motions. The occurrence and magnitude of slam loads are difficult to predict because of the non-linearity of the phenomena involved. Slamming causes local pressure loading on panels of plating and the associated stiffeners as well as excitement of the first several modes of hull girder vibration because of the impact energy associated with the slam.

Green sea loads, which may be from either heavy spray, or large slugs of water being thrown up at the bow, are

also highly non-linear. To date there is no analytic method of predicting these loads. Model tests have been used, although surface tension makes the physics of the water particles scale at a different ratio than the structural response, so such tests have to be used with caution. The most accurate load determination method is instrumentation of actual ships during storm conditions. The combination of prudent seamanship on the part of the ship's commanding officer, and luck, which frequently brings calm water during instrumented trials, means that the loads measured during short-term manned trials are less than the maximum that can be encountered during the life of a ship. However, the extreme non-linearity of green seas means that statistical means of extrapolation are not valid. The only certain method is to provide permanently installed strain gauges on a ship and a means of recording data at all times while the ship is at sea.

Local hydrostatic loads vary mainly because of the combination of wave height and ship's motion. In general, these phenomena can be predicted through the combination of wave statistics and linear ship response computations. However, for the extreme event, such as a breaking wave, computational methods are not available, so again, reliance on long-term data gathering is necessary to predict the extreme loads and their statistical variation.

Deck loads may vary in both magnitude and location, especially cargo, stores and aircraft landing loads. The current practice is to specify such loads in terms of nominal design loads, such as 75 pounds per square foot on decks above the weather deck. Such loads have been used for a long time with an associated factor of safety, but little has been done to predict their actual magnitude and their variability.

RESISTANCE

In the terminology of structural reliability, the strength of structure is referred to as resistance, an expression of the ability of the structure to withstand the imposed loads. Thus, the definition is directly related to the purpose of the structural system, which is to support other systems. The resistance of structure to loads is random in nature, with many factors, including fabrication defects, initial distortion of structure, defective welding, and misalignment of structural members contributing to the variability of the strength. Traditionally, limits on these factors are specified, and the structure is designed on the assumption that the minimum requirements are met. This approach is conservative, and the actual resistance of the structure will generally be greater than this minimum strength.

In many cases, the minimum requirements are not met in some areas in a completed ship. With the current means of design, there is no recourse other than to say that because the design criteria are not met, the structure must be reworked to meet all the specified requirements. This can be very costly, and in some instances, the additional residual stress introduced by structural rework can be worse than the original defects. A methodology is needed to determine the effect of the reduced strength on the probability of failure of the structure.

In addition to the variability in strength that comes from defects in workmanship, the actual strength of structural members is a random variable due to variations in the steel making process. The material properties such as elastic modulus and yield strength are random variables, as are other properties, such as thickness of plate and the depth and thickness of structural shapes.

An important mechanism by which ship structure can fail is by fatigue. In the past, attempts to apply fatigue analysis to ship structures have been unsuccessful because of the extreme variability of the load, as well as the variability of the strength of structure under cyclic loading. Figure 2 shows a fatigue diagram, where data points represent the number of cycles of stress reversal required to cause failure of a specimen when the amplitude of the reversing stress has a fixed value. For example, if a specimen of the type represented by figure (2) was placed in 10 ksi tension, and then in 10 ksi compression, and the process cyclically repeated, failure would be expected to occur after one million (10^6) load cycles. Typically, experimental fatigue data varies by two orders of magnitude in the number of cycles required to cause failure. For that reason, the data of figure (2) has three lines through the data. The center line represents the average or mean of the data, the upper line represents the one standard deviation upper bound, and the lower line represents the one standard deviation lower bound, which has an 84 percent probability of exceedance. A conservative approach is to design to this lower bound, but experience has shown that structure that has shown satisfactory service life may not meet these criteria.

To use this fatigue data in structural design when the amplitude of the stress is not the same from cycle to cycle, some form of cumulative damage prediction is necessary. The method shown to be proper for ship structures is the linear cumulative damage theory, or "Miner's Rule". [2] In equation form, this is expressed as

$$(3) \quad \sum_{i=1}^{B} \frac{n_i}{N_i} = K$$

where:

B = number of stress levels,
n_i = number of stress cycles in ith block,
N_i = number of cycles to cause failure at the ith stress level,

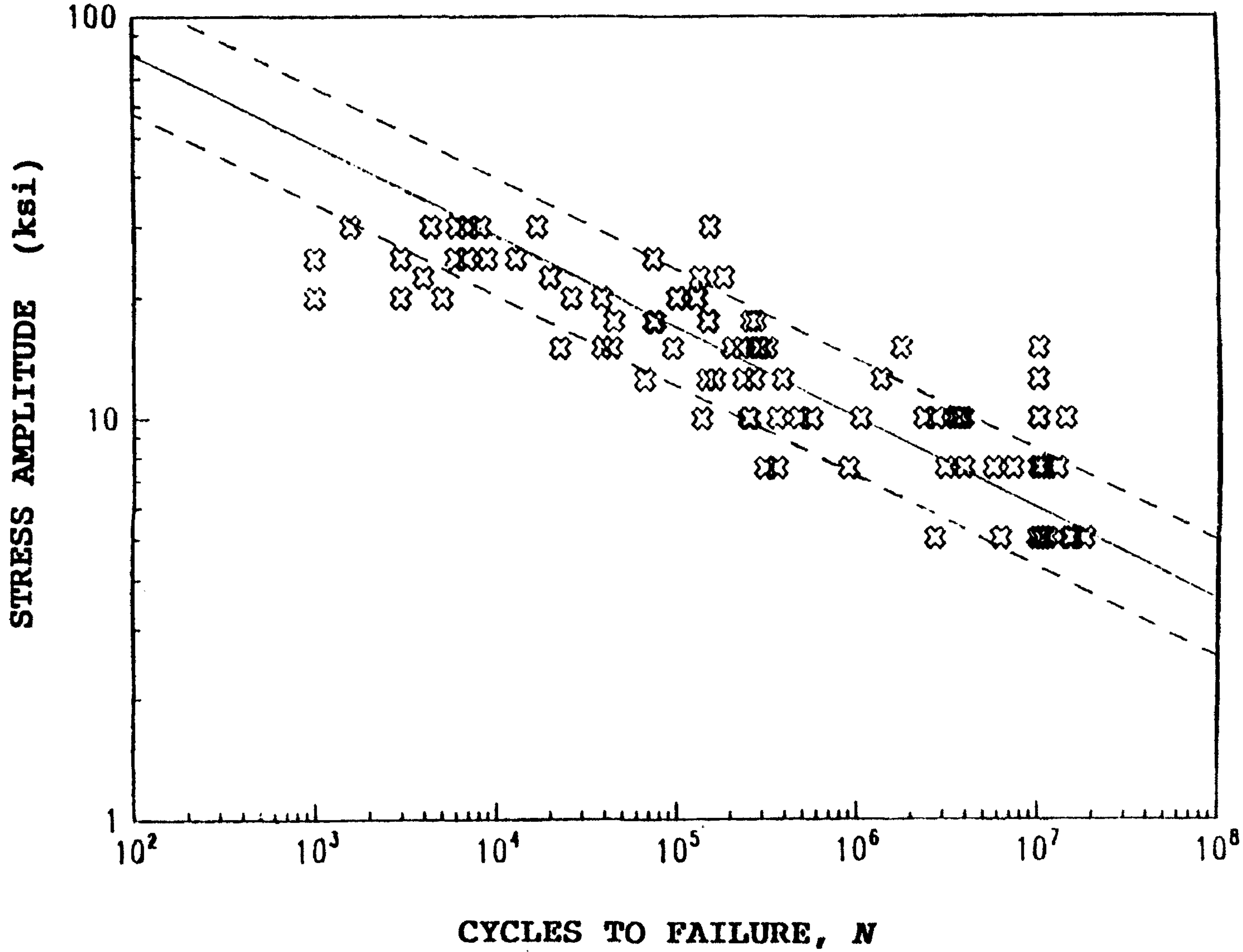

Figure 2 Fatigue Diagram for a Structural Section

K = summation constant (usually 1).

To use equation (3), the stress cycles imposed on the structure are divided into a number of blocks of equal amplitude. Suppose, for example, that the structure, whose fatigue strength is represented by figure (2) experienced 5,000 load cycles of 20 ksi, 100,000 cycles of 10 ksi, and 1,000,000 cycles of 5 ksi. Then application of equation (3) and the lower 5 percent probability line of figure (2) will give:

Block	n_i (Cycles)	Stress (ksi)	N_i (Cycles)	n_i/N_i
1	5,000	20	12,000	0.417
2	100,000	10	220,000	0.455
3	1,000,000	5	5,500,000	0.182
Total Cumulative Damage				1.054

In this computation, the total cumulative damage is 1.054, which is slightly greater than the summation constant 1.0, so failure of the structure by fatigue cracking should occur. The probability of failure under these specified loading conditions is 16 percent because that lower bound of the data contained in figure (2) was used.

Two things should be noted from the above example. The analysis required experimental data to determine the fatigue life. Because of residual stresses associated with welding as well as other irregularities associated with fabricated structure, analytic means of determining the fatigue strength of various structural details are not available. Some data is available on some structural details, such as that prepared for the SSC [3], but more work is needed to further characterize all the areas of ship structure which have proven to be points of crack initiation in the past. In addition to the need for data on structural details, a load history is needed. Because the load is a random variable, a method to use equation (3) with random loading is needed.

To combine all the variability in both load and resistance, a cohesive approach is needed which can address all the variables. The use of probabilistic structural design provides such a means, but its use is not straight forward, as many obstacles need to be overcome, of which one of the most important is the establishment of acceptable levels of reliability for ship structure.

WHY STRUCTURAL RELIABILITY ?

In spite of the problems that come from the variability of structural loads and resistance, apparently satisfactory designs have been produced in the past. The need for an entirely new approach can be questioned. "If it ain't broke, don't fix it!"

The use of probabilistic design represents a new approach, which is philosophically and academically more appealing than continuance with time-honored practice. If a new approach is available, it should be investigated to see what benefits as well as pitfalls it has to offer. In addition, it is likely that other ship designers are apt to use this new methodology in some way, and we in the Navy must be become familiar with this technology in order to evaluate proposals prepared in other than traditional methods. New ideas should not be rejected out of ignorance.

The benefits of this more rational approach have been seen by those in other industries, such as the offshore marine structures industry, which includes fixed and floating oil drilling and production facilities. The American Petroleum Institute, which sets industry standards, has recently promulgated standards for reliability based design with the cooperation of the U.S. Coast Guard and U.S. Minerals Management Service, which together provide regulation of offshore structures. In addition, the American Institute of Steel Construction, which sets the standards for most civil engineering structures such as buildings and bridges, has recently published standards in a reliability-based Load and Resistance Factor Design (LRFD) format.

The use of probabilistic design has the potential for enhancing the quality of the system. With current deterministic procedures, there are uneven levels of reliability built into design criteria, with some areas of structure having much greater safety than others, so that overdesign in these areas produce weight and cost penalties.

With the current criteria, there are many variables that are not directly addressed, but only provided for through the use of factors of safety in design allowable stress. A detailed accounting of the uncertainties has the benefit of identifying their effect on design, and either relaxing or tightening standards in some areas so to reduce overall weight and cost. In this way the safety margins within a class of structures and within the same structure can become more consistent.

These are compelling reasons to use this method for traditional ship designs. More importantly, for new structural configurations for which we have no precedent, it is the best approach. When loads must be determined through either experimental or analytical means, or some combination of these, the result can only be stated in a probabilistic manner. Likewise, for new structural configurations, the strength can only be stated as a random variable, especially if the governing condition is fatigue failure. The most conservative approach is to design so that the minimum strength possibly available is greater than the maximum load possibly occurring, but that approach is not used for conventional designs, and

can therefore be assumed to be over-conservative and lead to excess weight and cost for non-conventional designs.

Lastly, the use of some measure of probability is necessary when considering fatigue strength because of its inherent variability. In this case, especially when evaluating the acceptability of defective structure, the use of the probability of crack initiation has been found to be a necessary tool to avoid overly conservative repair criteria. A considerable amount of money is spent each year to repair cracks that occur in ship structure. With probability of failure estimates used in design calculations, the cost benefits of a more reliable design can be quantified. Reliability analysis provides a means of assessing the total effect of defects in welding, and it is possible that inspection requirements can be relaxed if they are thoroughly analyzed.

Of course, the benefits of job security for structural engineers is not to be denied. The new practice of necessity involves more engineering time, although that should be more than offset by the benefits of the associated reduction in weight and cost for ship structures. The challenge is to implement this technology in a manner that will least impact ship design cost and schedule, yet provide all of the inherent benefits of the method.

PAST EFFORTS IN STRUCTURAL RELIABILITY AND APPLICATIONS

Aluminum Deckhouse Cracking

During the early 1980's, it became apparent that a class of ships which had continuous aluminum deckhouses had a structural problem. It appeared that fatigue loading was causing cracking of that aluminum structure. To prevent further occurrences of the problem, an acceptable design solution was necessary for reinforcement of the structure. If that could not solve the problem, it would be necessary to backfit the deckhouse with traditional expansion joints. Analysis of the structure and possible solutions had to deal with the variability of fatigue data. The final design solution had to be a compromise between the cost of backfit and the cost of repair, which would include lack of availability of the ship during unanticipated repair times. In this case, the greatest consequence of cracking of the deckhouse was loss of ship availability because of the need for repairs, but was not so serious as to lead to catastrophic hull failure, so that the final backfit repairs that were implemented had a 30 percent probability of cracking in 30 years of service.

Swath Ship Design

During the recent design of a SWATH ship, examination of load predictions and structural design based upon conventional practice with nominal loads determined from model tests indicated that prevention of failure by fatigue would be the controlling factor for acceptable stress levels. If unattended, a small fatigue crack could eventually lead to failure of the hull, but fatigue crack growth studies indicated that sufficient time would exist between the discovery of a crack and the time that it would reach a critical size so that repairs could be made before total failure occurred. Consequently, the design stress was based upon three percent probability of failure in 20 years, and 50 percent probability of failure in 60 years of service.

Investigation of Defective Short-arc Welding

As a method of increasing shipyard producibility, several commercial shipyards began using the gas metal arc short circuit transfer (Short-arc) process in the 1970's for U.S. Navy ship construction. Certification of this process included a requirement for back-gouging of welds prior to the final weld passes, but this step was frequently omitted during construction, which led to many partial penetration welds in critical regions of ship structure, especially in butt joints of longitudinal stiffeners. An extensive program involving the testing in the laboratory of sections removed from ships was undertaken to determine the consequence of these defective welds. It was determined that resistance to failure through a single application of either tensile or compressive stress was not significantly reduced. However, fatigue failure of the welds was determined to be a major issue, as the testing showed that the strength of the welds was reduced by as much as 50 percent under repeated loading. These defective welds were widespread throughout several classes of ships, and repair of all of them would be extremely expensive. To evaluate the loss of service life of the ship structure caused by these defective welds, fatigue analyses were made. In the case of one class of ships, the decision was made to undertake a surveillance program rather than to begin repair of all defective welds. This decision was based upon the prediction of 30 percent probability of cracking in 30 years of service.

ISSUES IN IMPLEMENTING PROBABILISTIC STRUCTURAL DESIGN

At present, the loads to which ship structures are subjected are not fully understood. Even hydrodynamic loading from waves can not be predicted with accuracy. The method currently used for load prediction for convention-

al surface ships uses linear seakeeping theory (strip theory). However, because of the linearity assumed in strip theory, where the response amplitude operators are assumed to be the same for one foot waves as for 30 foot high waves of the same frequency, it can not accurately account for effects such as extreme waves. Strip theory programs can not compute slam-induced hull girder whipping, where the impact from either the bottom of the ship or flare regions in the bow striking the surface of the water will excite the first several modes of hull vibration, leading to bending moments equal in magnitude to as much as 50 percent of the maximum wave induced hull bending loads. Failure to account for these non-linear events can lead to significant under-estimation of loads when the use of linear seakeeping computer codes is used for the prediction of design loads. [4]

Even when accurate methods of predicting hull girder bending and other hydrodynamic loads are developed, the inherent randomness of the seas that produce these loads necessitates a probabilistic basis for their use. An option is to use some statistical indicator of maximum load intensity, such as the one thousandth highest load expected in sea state nine, or the maximum expected load over a thirty year service life, assuming some operational profile for the ship. The problem with such statistical measures is that an appropriate design stress and factor of safety on collapse must be associated with the load condition. Unless the technique is calibrated with existing ship designs, the weight of the structure for a new ship design could increase significantly only because of a somewhat arbitrary change in design criteria.

There are other traditional loads used in ship design which have no probabilistic basis, but were determined through examination of the maximum anticipated service load. An example is the 75 pounds per sq.ft. used for deck loads in some areas. For these loads, either the continuation of deterministic design will be necessary, or surveys of actual conditions aboard ship, including the extreme cases, will have to be made to form some sort of statistical distribution.

Some loads are used in ship structural design whose magnitudes are relatively unknown, and design criteria are determined mostly through engineering judgement. An example of these loads are green seas loads, for which no explicit design criteria exist for areas of the structure such as the deckhouse front. Slamming of the bottom has been studied more extensively, but the time-space history of pressures on the surface of the hull is needed along with the fluid-structure interaction equations to determine structural response. Accomplishment of this has not been done to date, and structural design relies upon nominal average design loads, such as applying a hydrostatic head to 12 feet above the weather deck. These uncertainties in loading are accounted for by the use of traditional factors of safety which when used in design has achieved satisfactory service. However, in some cases, structural designers have traditionally used arbitrary increases in scantlings in some areas where the nominal loads seemed to be insufficient, so that the adequacy of conventional design criteria can not always be judged by numbers alone.

The resistance of structure to loads (structural strength) is not fully understood. Current design criteria, such as the buckling strength of members, are based upon some initial imperfections in the structure. However, the means to accommodate variance in the structure must be developed. In addition to understanding the effect of construction tolerances on strength, and indication of the variability of such deviations is necessary to determine the probability density function of the strength. In addition to current specified values, knowledge is needed of the variability of material properties such as yield strength.

IMPLEMENTATION IN FUTURE DESIGNS

Full implementation of probabilistic design will require an interface between several technical codes within NAVSEA, including the Structural Integrity Subgroup (NAVSEA 55Y) for design, Hull Form and Hydrodynamic Performance Division (NAVSEA 55W3) for loads determination, and the Materials Engineering Subgroup (NAVSEA 514) for establishment of fabrication and welding criteria. Close work with research establishments such as the David Taylor Research Center, particularly the Ship Structures and Protection Department (DTRC 17) and the Ship Hydrodynamics Department (DTRC 15) will be needed for better description of loads, resistance, and computational methodology. Additionally, coordination is necessary with the NAVSEA ship design manager and the OPNAV sponsor. Requirements for structural reliability should be specified at the TLR level, but that can not be an arbitrary decision. To define an acceptable probability of failure requires education of and dialogue with the Ship Characteristics and Improvement Board and others in OPNAV. To begin with, we must define what is meant by "failure". In some cases it will be crack initiation, which among other things, will lead to repair expenses. Total collapse of the hull, on the other hand, can never be permitted under conditions other than from wartime weapons effects. Loss of serviceability from localized buckling, like crack initiation, can be more of a nuisance nature, assuming that timely repairs can be made before total collapse occurs. For these different failure modes, different levels of reliability can be accepted, but this can be done only after a full assessment of the consequences of failure.

In addition to the development of acceptable reliability levels, the operational scenario upon which reliability estimates are made is very important. For convenience because of the large amount of sea state data available, most computations are based upon operations in the North Atlantic, with 50 percent operability assumed. Typically, a 30 year service life is also assumed. Actual operating conditions may vary significantly from these, and are usually less severe, but if a ship is designed to operate in a benign environment, the consequence of changing operational scenarios during a ship' lifetime must be considered, as strengthening a ships hull structure once completed is a very expensive proposition.

Implementation of reliability methods in design for "conventional" ships may be as a LEVEL I LRFD approach. The difference between LRFD design and the current factor of safety design is that rather than arbitrary judgement, the factors are determined through reliability analyses so that a desired structural reliability is achieved. To determine the load and resistance design factors, it will be necessary to perform analyses of existing ships to determine current reliability levels. However, the factors should be adjusted to remove any inconsistencies in design, and thus result in more uniform levels of reliability throughout the structure. For the structural designer, little change in procedure will be noted from conventional methods of design.

For new ship types, probabilistic means will be used to determine design loads and to determine acceptable design stresses. The assumption will be that acceptable reliability for similar modes of failure will be the same as for more conventional ships, unless there is some reason for the new ship type to adopt different standards.

CURRENT EFFORTS TO DEVELOP RELIABILITY TECHNOLOGY

A major commitment to develop reliability theory for ship structures has been undertaken by the interagency Ship Structure Committee (SSC). This organization, with representation from NAVSEA, the Military Sealift Command, U.S. Coast Guard, Maritime Administration, and the American Bureau of Shipping annually sponsors about $600,000 in structural research. To kick off the program, SSC cosponsored a symposium and funded a tutorial on structural reliability to inform the marine community of this new technology. Sponsored by SSC and SNAME, the Marine Structural Reliability Symposium was held in Arlington, Virginia, October 1987. [5] It attracted experts from around the world and provided a forum for assessing the state of the art in reliability methods. Under SSC sponsorship, Dr. Alaa Mansour of the University of California, Berkeley, prepared a tutorial document [6] and offered a one week seminar to SSC participants and colleagues in San Francisco in January 1988. He offered another seminar with SSC support in November, 1990, in Crystal City, Virginia, which was well attended by engineers from NAVSEA and the associated ship structures community. Following up on these initial efforts, there are seven other SSC projects in reliability either ongoing or planned for the next three years.

Under the Surface Ship Exploratory Research (6.2) program "Structural Fitness for Service" at DTRC, a major effort has been planned for FY 88-93 to develop probability theory for surface ship structural design. Specific goals are: Preliminary Assessment of Probabilistic Design Technology for Naval Ships, FY 88-89, Probabilistic Methods for Ship Static Strength Analysis, FY 90, Guidelines for Life Cycle Failure Assessment, FY 91-92, and Probabilistic Design Data for Naval Ships, FY 92-93. Other efforts within the 6.2 program will support the development of probabilistic design by developing the statistical data needed, including impact loads, extreme loads, ultimate strength, fatigue loads and material strength, instability analysis, fracture mechanics, and other aspects of ship structural analysis.

To implement structural reliability theory, both hydrodynamic loads and structural strength must be described far more accurately than in the past. To develop this loads and resistance technology, as well as structural reliability procedures, NAVSEA in FY 92 will begin a major Advanced Development (6.3) research program that will complete in FY 97. Under this program, an extensive series of hydrodynamic loads projects will be conducted, including measurement of loads at sea, instrumented rigid-vinyl models tested in wave tanks, and use of the latest state-of-the-art hydrodynamic loads prediction tools, by which load estimates will be compared for the purpose of accurately defining the probability density function of all extreme loads, including such highly nonlinear events as slam induced whipping. Structural resistance to the loads will be developed through an extensive series of tests of structural models, ranging from small specimens of structure, to large scale models of ship structure which will be tested to determine strength under conditions of compressive buckling failure, fatigue, and fracture. The loads and resistance projects, in addition to providing more accurate data to supplement current U.S. Navy structural design criteria, will provide sufficient data to statistically define both the structural loads and resistance. With this statistical data base, methods of structural reliability analysis will be evaluated to propose design criteria for future ships. These design criteria will be calibrated through reliability analysis of existing ships so as to help define an acceptable level of structural reliability.

A major effort to begin the structural loads determination has been done as part of the investigation of the structural

design of a major warship. A 1/25 scale self-propelled rigid vinyl model has been constructed and is undergoing tests in waves in the DTRC towing tank and MASK facilities. A ship of this class was extensively instrumented with more than 100 strain gauges, and during a one week period in January 1991, underwent trials in heavy weather conditions, including sea state six, so that a significant amount of data was collected, including nonlinear slam-induced hull whipping. A mathematical model of the ship hull structure was made using the finite element method, so as to correlate measured strains in the rigid vinyl model and in the ship with load predictions. In addition, seven different hydrodynamic loads and motions computer programs will be exercised for this ship under identical sea conditions and the results compared with the model and full scale results to indicate the ability of these computer programs to predict loads.

CONCLUSIONS AND RECOMMENDATIONS

Probabilistic Structural Design is a tool which will allow us to make much progress in Ship Structural Design for both new and unusual ship types and for conventional ships. We are making some progress to implement the technology, and hope to overcome a lack of data through an extensive research program as well as cooperation with other agencies with similar goals. However, as has been seen, probabilistic assessments have been used in the past for design and repair decisions, and not doubt will continue in the future. Therefore, as the development of technology continues, it will be implemented in design as appropriate.

The payoff will be great. The immediate results will be a reduction in structural weight and cost as inconsistencies inherent in the current procedures are eliminated. Through the application of improved technology, even further gains will be made in the reduction in structural weight, with no decrease, and possibly with an increase, in structural reliability, and an associated reduction in maintenance costs. Even greater gains are anticipated in the cost reduction that will come from the safe and reliable introduction of new structural configurations and fabrication techniques intended to enhance ship producibility.

All means of enhancing the technology of ship structural design must be encouraged, for now we have the framework for incorporating new concepts into the design process. Planned research programs must be fully supported to ensure their continuation and the advances in ship design that will follow.

REFERENCES

[1] Sikora, J., Dinsenbacher, A., and Beach, J., "A Method for Estimating Lifetime Loads and Fatigue Lives for SWATH and Conventional Monohull Ships", ASNE Journal, May, 1983, pp. 63-84.

[2] Kihl, D.P., T.F. Brady, and J.E. Beach, SUMDAM: A Computerized Linear Cumulative Damage Approach to Estimating Fatigue Life Of Surface Ship Structures, DTNSRDC Report SSPD-88-173-37, April 1988.

[3] Park, S.K. and F.V. Lawrence, Jr., Fatigue Characterization of Fabricated Ship Details for Design Phase II, Ship Structure Committee Report SSC-346, May 1988.

[4] Clarke, J.D., "Wave Loading in Warships", I.N.S., Vol. 12, 1986, pp. 202-216.

[5] Ship Structure Committee and the Society of Naval Architects and Marine Engineers. Proceedings of the Marine Structural Reliability Symposium, October 5-6, 1987. New York: Society of Naval Architects and Marine Engineers, 1987.

[6] Mansour, A., An Introduction to Structural Reliability Theory, Ship Structure Committee Report #351, January, 1989.

FORGING THE FUTURE: NAVAL SHIPYARD CORPORATE OPERATIONS STRATEGY AND PLAN

Margaret R. Bianco
Corporate Strategic Planning Manager
(SEA 07211)
Naval Sea Systems Command

Kurt C. Doehnert
Industrial Engineering Branch Head
(SEA 07213)
Naval Sea Systems Command

Abstract

The Naval Shipyard Corporate Operations Strategy and Plan (COSP) establishes aggressive pursuit of excellence in three key areas: cost/schedule performance; technical excellence and human resource strategy; and environmental compliance for the Naval Sea Systems Command, Industrial and Facilities Management Directorate (NAVSEA 07) and the naval shipyards. The COSP, signed 30 May 1990, is a result of joint headquarters and shipyard strategic planning sessions and incorporates many initiatives, from the Naval Industrial Improvement Program (NIIP), as well as recommendations from the Ship Depot Maintenance Study conducted in 1989. The COSP provides definitive guidance for performance improvement in the areas of direct and indirect costs, schedule adherence, material costs, technical excellence, capital plant management, safety, human resource strategy and environmental compliance. The COSP has specific objectives and establishes both short and long range measurable goals.

The COSP, coupled with Total Quality Leadership (TQL), "getting back to basics", and implementation of new tools, provides the foundation and framework for naval shipyard industrial and facility management over the next five years, 1991 - 1994, and sets the stage for improved future operations. This paper examines the development, content, and implementation plan of the COSP. The purpose of this paper is to increase awareness and understanding throughout the Navy community of the naval shipyard commitment to meet the challenges of today and tomorrow. Admiral Kelso, Chief of Naval Operations (CNO), addressing senior shipyard managers recently stated, "I need for you to succeed in this job because I think that the size of our Navy depends upon you and what you're doing."

INTRODUCTION

Background

Naval shipyards exist to support the Fleet. Their primary mission is to repair, overhaul, drydock, and convert aircraft carriers, surface ships, and submarines, and to provide logistics services in support of fleet readiness. Naval shipyards are also responsible for other functions ranging from research and development to nuclear refueling. The naval shipyards provide a ready work force capable of accomplishing highly complex and classified workloads. At the end of FY 90, 66,000 civilians were directly employed in the naval shipyards. The FY 1990 naval shipyard budget was $3.9 billion. Naval shipyard customers are Fleet Commanders, Type Commanders and NAVSEA.

The eight naval shipyards are strategically located in Portsmouth, New Hampshire; Philadelphia, Pennsylvania; Norfolk, Virginia; Charleston, South Carolina; Long Beach, California; Mare Island, California; Puget Sound, Washington; and Pearl Harbor, Hawaii.

Naval shipyards operate under the Navy Industrial Fund (NIF). Operating capital is provided to the naval shipyards by the NIF. As work progresses, the NIF is reimbursed by fund transfers from the customers. Unlike the private sector there is no profit motive. The goal is to have revenue equal cost.

OPNAVINST 3050.22, Strategic and Operational Requirements for Naval Shipyards, demands that naval shipyards:

- have a responsive, geographically dispersed, strike-free, industrial capacity;
- have a qualified, available work force whose priorities are controlled by the Navy;
- ensure support of highly complex and classified workloads;
- maintain the immediate capability to repair battle damage on all ship classes; and
- provide an immediate industrial mobilization base.

History

The requirement for ship depot level repair facilities is fundamental to the Maritime Strategy of the Nation and the Navy. The Navy has always recognized the need to retain the strategic and mobilization features of the naval shipyards.

In the early 1960s the naval shipyards were heavily workloaded, with nearly 100,000 employees in eleven naval shipyards. Over the 30 year history of the NIF, many initiatives resulting from numerous depot maintenance operations studies, GAO findings, and mandates to identify and control NIF costs and improve schedule adherence have been undertaken. Most efforts were attempts to correct problems within the shipyards, without regard for external influences. Consequently, problems persisted in the form of excessive overhaul delays and rising costs.

In early 1980, the naval shipyards were under scrutiny when schedule delays, primarily in submarine overhauls, created an unacceptably large number of lost ship operating months. To respond to CNO and Fleet concerns, NAVSEA developed a comprehensive set of Ship Depot Maintenance Policies and established the Depot Operations Improvement Program (DOIP). The primary objective of the DOIP was to improve schedules, believing that costs would naturally come down. A secondary objective was to return more operational control to the Shipyard Commanders and allow them autonomy within general NAVSEA policy. Several decisions were made to facilitate this end, personnel ceilings and overtime controls were removed, non-complex surface ship overhauls went to the private sector, and extended durations were approved.

A Shipyard Operations Review Team (SORT) was established, comprised of shipyard and headquarters personnel. On-site reviews of individual shipyard operations were conducted by the SORT, reporting findings and recommendations to the Shipyard Commander and COMNAVSEA. Priority and emphasis was placed on schedule performance, and to that end, schedule adherence improved significantly. However, costs and overtime use increased substantially and once again critical attention was focused on the naval shipyards, this time to reduce costs.

In 1985, the Secretary of the Navy (SECNAV) placed employment controls at the shipyards, with the emphasis on reducing cost and "to allow overhaul duration to be determined by each shipyard's most effective working tempo." Shipyards were being pressured to operate more and more like commercial businesses. It was during this period that the naval shipyard mission element to "maintain an immediate capability to repair battle damage on all ship classes" was questioned.

Major force structure changes, budget reductions, loss of commercial new construction work, foreign shipyard subsidies, improved maintenance philosophies, all portended declining workloads. Pressure increased for the naval shipyards to improve productivity and reduce costs, or become candidates for closure. Competition for limited resources had intensified. At the same time, in preparation for POM 87, SECNAV directed that $500M be removed from the fleet maintenance program, with the strict understanding that the amount of real ship work to be accomplished in 1987 would not be reduced. Thus a 17% instantaneous efficiency was mandated across the board in the naval shipyards to "force" improvement. At the same time Congressional interest in expanding public/private competition was escalating.

The Navy was committed to a more modern and larger Fleet. Naval shipyards had a major role in supporting expansion towards the 600 ship Navy. Since previous efforts failed to bring about long lasting shipyard improvements, SECNAV directed that comprehensive assessments be performed on all NIF-funded activities (naval shipyards, aviation depots, ordnance stations and public works centers) as well as their headquarters, to determine what the problems were, and to compare public sector business practices with the private sector. These assessments were specific recommendations for improving the management of naval shipyards. The services of management consultants with expertise in government and private industrial functions, were retained to conduct this appraisal and resulted in 129 recommendations in seven functional areas:

- General Management
- Operations
- Engineering

- Organization
- Materials Management
- Financial Management
- Management Information Systems

In 1986, after a review of the management consultant report, SECNAV established a program to implement the resultant recommendations, the Naval Industrial Improvement Program (NIIP), which was charged with introducing and institutionalizing change in two key areas:

- Centrally administered rules and procedures; and
- Work methods, procedures and processes.

The NIIP consisted of three phases:

Phase I, 1984 - 86, Survey assessment by Coopers and Lybrand

Phase II, 1986 - 87, Pilot projects in select shipyards

Phase III, 1987 - 91, Roll out of the high payoff initiatives

During the pilot phase, several projects at different shipyards tested the feasibility and value of new management methods. Project planning and execution was a joint effort of NAVSEA 07, shipyard representatives and the NIIP Program Office. The NIIP was the foundation of initiatives for improving the operating efficiency of the Navy's major industrial activities. All NIIP improvement projects (including the other NIF activities) had the same four basic themes:

- Match accountability and authority with responsibility;
- Decentralize;
- Balance cost and schedule; and
- Manage in a business like manner.

During the roll out phase projects were duplicated in other yards, using lessons learned from the pilot phase. The NIIP underwent rigorous reviews during this period. The results were to prioritize and institutionalize initiatives that proved to have high payback potential and to discontinue initiatives that had minimal return. The NIIP served as a valuable resource for NIF activities, providing technical assistance, and acting as a catalyst for the implementation of sound business practices.

The principle difference between NIIP and previous improvement initiatives was its focus on improving operations instead of simply reducing budgets. The NIIP represented the Navy's commitment to effect change, and has evolved into the current environment in which headquarters and naval shipyards provide ownership and control over continuous self-improvement.

In 1988, Deputy Chief of Naval Operations (Logistics OP-04), established the Ship Depot Maintenance Flag Steering Board to provide central oversight and expedite necessary action to address problems and make specific recommendations for corrective action. This study took a broad view of problems in ship depot maintenance operations. In addition to reviewing naval shipyard problems, the study examined OPNAV, NAVSEA, Fleet and NAVCOMPT roles in the total process that determine shipyard workload and resource requirements. The Flag Steering Board Final Report was presented and approved by SECNAV on 13 December 1989. The outcome revealed five key principles of improvement across the ship depot maintenance process: Discipline, Definition, Uniformity of Planning, Strong Process Management and Balancing the Workload.

SECNAV assigned implementation of recommendations and goals for internal shipyard improvements to COMNAVSEA in cooperation with CNO, and NAVCOMPT, who report to ASN(RD&A). For those improvements external to COMNAVSEA, OP-04 has direct responsibility, with the support of NAVSEA and NAVCOMPT. At this time, SECNAV established the Naval Industrial Review Council (NIRC) whose purpose is to ensure corrective measures will be implemented at all industrial activities.

Under the leadership of the Secretary of Defense, the Defense Management Report (DMR) was submitted to the President. The DMR established a DoD FY 91-95 savings goal of $30B. These savings are to be used to help reduce the DOD budget without programmatic reductions. Naval shipyards are included in the DMRD budget reductions and are committed to achieving savings of $1.6B during FY 91-95 through vigorous implementation of the COSP. Quarterly status reports are submitted to Department of the Navy Management Report Implementation Coordination Office (DONRICO) and are used as an internal navy management tool.

COSP DEVELOPMENT PROCESS

Numerous internal and external pressures demonstrate a compelling need for productivity gains in the naval shipyards. The common thread is that the capability of shipyards should be to maintain full utilization in

peacetime, and to provide an industrial base to support wartime requirements. Improvement can come only through lasting changes in processes and achieving a degree of uniformity among shipyards. Major decisions need to focus on the ability of the naval shipyards to serve present and future customers, within the limited capital resources available in a rapidly changing environment.

It was apparent that a Long Range Business Plan to improve operations over the next five years was overdue. External impediments could not be an excuse. The community had to get internal shipyard problems under control and demonstrate a corporate resolve to implement long term improvements. A plan was needed to confront the current operational environment within the Defense Department which was shaping the future of naval shipyards. The approach required focus on long term objectives while staying flexible enough to solve day-to-day problems and concurrently being able to recognize and take advantage of new business opportunities. The goal was to find a balanced system for shipyard improvement which would avoid reacting to long term problems with short term solutions. Ongoing successes were to be encouraged and perfected, then exported to all yards in a systematic manner. Selective implementation was no longer an alternative.

Rather than develop a Corporate Operations Strategy and Plan from within headquarters, as was done with an earlier version, active shipyard involvement was encouraged. In January 1989, the Shipyard Board of Directors was convened to establish a coordinated corporate approach, using a structured and methodical process, for deciding what the organization will do today to ensure success tomorrow.

A cooperative relationship, in which contractors designed the structure and facilitated the planning process, and the Shipyard Board of Directors participated in the development and implementation of a long range plan was initiated. The basic elements included: business mission, environmental scan, situation audit, key accomplishments, strategies, long range goals, objectives, feasibility checks, individual action plans, contingency planning and progress review.

The next step was to incorporate results from:

- Ship Depot Maintenance Study;
- On going shipyard/headquarters and NIIP initiatives
- Strategic Planning sessions with Shipyard Commanders
- Current operational environment (DMRDs, Downsizing, Base Closure, etc.);
- Headquarters meetings leading to a revision of the
- Corrective Action Strategy which included more detailed POA&Ms; and
- 13 December 1989 action items from the COSP briefing to SECNAV

Through the strategic planning process, improved communications and mutual problem solving among the shipyards and headquarters have evolved.

COSP OVERVIEW

Section I of this paper provided a brief overview of the naval shipyards, their mission and business environment, and a historical perspective of events leading to initiation of the COSP. Section II described the process and actions by which the COSP was developed. The purpose of this section is to provide an overview of the 150 page COSP structure and contents.

The COSP was officially issued on 30 May 1990 when it was approved by RADM D.H. Hines, then SEA 07, by his signature on the cover page. While the COSP is in fact a document, it is important to recognize that this document is actually the means to an end, that being improvement in naval shipyard operations and performance, rather than an end in itself.

The COSP is logically organized and structured to reflect the outcomes of the strategic planning process. The introductory sections provide an overview of the COSP purpose, the background leading to the need for a corporate plan, and the rationale for the plan strategy and direction. The content of these introductory sections, is summarized in Sections I and II of this paper. Additionally, the introductory section clearly establishes the application of Total Quality Leadership (TQL) principles and techniques as the driving force to achieve performance improvement on a continuing basis. The COSP has a hierarchical structure built on a) three key issues, b) nine functional areas, and c) 57 action items.

The corporate strategy for managing the changing environment in the 1990's starts with driving the cost of ship maintenance down and getting the ships back to the customer on time. The areas of cost and schedule performance, technical excellence and human resource strategy, and environmental compliance have been identified as the three key areas that need improvement in order to meet the strategic goals. These key issues are defined as follows.

The first key issue is Cost and Schedule Performance, and the required key accomplishment is to realize improvement in these areas. In order for this to be accomplished, the workload must be balanced with the work force. To optimize performance, this balance must be made down to the skill level. A major issue given the current scenario of workload reduction and work force downsizing is retention of necessary skills. The process of work planning must also be optimized. Furthermore, shipyards must improve the management of facilities and equipment. The Stabilized Manday Rate, which is the cost to the customer for work performed, must be reduced. And, shipyard managers must be trained to provide effective leadership in a rapidly changing environment.

The second key issue is Technical Excellence and Human Resource Strategy. The key accomplishment in this area is that a standard of excellence will exist within the shipyard community which will result in delivered products being technically correct in all respects. Quality must be built into the process, rather than "inspected in". A coordinated approach to improving technical work documents, production and technical skills training, and supervision is required. The approach will be to create an environment in which to establish and maintain high standards of excellence, including adequate personnel resources, professional work places, state of the art equipment, professional, technical and managerial training and development, and a system for interchange to take advantage of technical knowledge and expertise. Coupled with this approach is the strategy to improve human resource management as an integral element.

The third key issue is Environmental Compliance, and the goal is for naval shipyards to be recognized for compliance with local, state, and federal environmental protection requirements. There are increasing requirements as well heightened public awareness and demand for action. The approach is to become increasingly proactive, including a process to ensure strong commitment and continued awareness at all levels.

The COSP establishes specific plans of action to address the three key issues/accomplishments discussed above. This plan is built on nine functional target areas as follows:

COSP Key Issues/Functional Areas:

Key Issue No. 1: Cost and Schedule Performance
- 1A. Schedule Performance
- 1B. Direct Labor Cost Performance
- 1C. Overhead Cost Performance
- 1D. Material Cost Performance
- 1E. Improved Capital Plant Management

Key Issue No. 2: Technical Excellence and Human Resource Strategy
- 2A. Technical Excellence
- 2B. Safety Enhancement
- 2C. Human Resource Strategy

Key Issue No. 3: Environmental Compliance
- 3A. Environmental Compliance

For each of these nine functional areas, there are attributes established as follows:

a) a Definition of that area which is a clear, concise statement of what it entails; for example, 1B, Direct Labor Cost Performance - all labor that is directly charged to the customer for a specific availability;

b) a listing of the general Changes Required within that area which summarizes the significant changes which must occur for success; for example, 1B, Direct Labor Cost Performance - increase use of project management;

c) identified Target Goals which set the level of results; for example, 1B, Direct Labor Cost Performance - 5% productivity improvement in shipyard direct labor within first year;

d) the Action Plan listing the specific actions to be taken under that functional area (further discussed below); and,

e) a means for Performance Measurement in order prescribe the means to measure the results of improvements in that area; for example, 1B, Direct Labor Cost Performance - cost performance index, using C/SCS on project ships.

There are a total of 57 action items in the COSP, each under the applicable functional area. Appendix A provides a listing of all of the action items in the COSP, grouped by the functional areas. Like the functional areas, each of the individual action items has a standard format. First, there is a clear statement of the Action. Second, a Background section provides an overview of the need for, intent of, and expanded statement of the action. Third, there is specific measurement criteria established for that action. The NAVSEA 07 point of contact for the action item is also designated. Though grouped together in a separate section at the back of the COSP, each of the 57 action items also includes a Gantt Chart which outlines the subtasks, including responsible action organization and timeframes, required for that action.

COSP IMPLEMENTATION AND MANAGEMENT PLAN

To reemphasize a prior point, the COSP is only a plan to achieve naval shipyard performance improvement. As with any plan, the key to achieving results is in implementation. Given the overall significance of the COSP, its efficient and effective implementation required a well thought out approach for its deployment and implementation, both in organization and action.

Before further addressing the COSP implementation plan, it is important to note that the COSP is considered a "living" document, subject to change consistent with fundamental strategic planning principles and the TQL principle of continuous improvement. This concept is also consistent with the TQL Plan, Do, Check, Act (PDCA) cycle. That is, for any action, the PDCA cycle says to first plan the activity, then take action, check the results, and act based on the facts. Therefore, the COSP implementation and management plan was designed to address the initial plan implementation and its life cycle management.

A COSP Management Plan has been established for the implementation and ongoing management of the COSP. This organization is headed by the Shipyard Board of Directors (BOD), which is comprised of all of the Shipyard Commanders, SEA 07 senior management, and SEA 08X. The BOD provides program policy and management oversight, and serves as the decision making body for any changes to the COSP.

The next level of this management plan is the COSP Advisory Group which is comprised of SEA 07 representatives, the Chairman of the Naval Shipyard TQL Principals Network, and the designated COSP Coordinator from each shipyard. The COSP Advisory Group serves in a staff position to the BOD, and functions as the shipyard advocate for addressing major COSP issues and concerns, and to ensure that all improvement efforts in naval shipyards are integrated and aligned with COSP objectives.

Another key organizational element is the TQL Principals Network whose members are the TQL advocate from each shipyard and SEA 07. Their primary function is to influence implementation and management of the COSP consistent with the principles and practices of TQL.

The final element of the COSP management plan organization is the Functional Area Managers (FAMs); that is, for each of the 9 COSP functional areas, there is a Headquarters FAM and a Shipyard FAM at each of the shipyards. The FAMs are responsible for managing the implementation of the assigned functional area and its subordinate action items at their activity.

Deployment of the COSP implementation plan was formally initiated at the end of July 1990. The Shipyard Commanders, Shipyard COSP Coordinators, and Shipyard FAMs were all brought to NAVSEA for a high level meeting to initiate COSP implementation. The primary purpose of this session was a Headquarters FAM meeting with the Shipyard FAMs to brief and discuss the assigned functional area. This provided a common denominator and served as the basis for roll-out of the plan uniformly throughout the corporation. The highlight of this meeting was the direct involvement of Admiral Kelso, Chief of Naval Operations, as the guest speaker at a special banquet. In his remarks, Admiral Kelso commended the shipyards for rising up to meet the challenges of today, emphasized the importance of the task, and offered his support.

The COSP kick-off meeting served as the platform for the Shipyard FAMs to go back to their shipyard and execute the second step of the implementation plan, which was to deploy the COSP throughout their shipyard. More importantly, the shipyards could then begin their internal planning for COSP implementation. It is important to note that several shipyards had already developed a shipyard strategic plan for their yard. Ideally, the corporate plan (COSP) would have come first, and served as the "top down" basis for the shipyards' individual plans. However, given the circumstances, several shipyards were faced with integrating their own plan with the COSP. The SEA 07 position on this issue is to allow the shipyards flexibility to have local shipyard goals, objectives, and action items to address their local needs and mission objectives. This position recognizes the differences in culture, performance, and progress across the eight shipyards. However, the COSP takes precedence; that is, priority will be given to the COSP functional areas and action items.

The next critical step in the COSP implementation plan was conducted during October - December 1990. During that time, a team of SEA 07 managers, primarily the Headquarters FAMs, conducted a two day on-site review at each shipyard. This initial visit was intended to be informational in nature and to evaluate the shipyard's implementation of the COSP since the kick-off meeting. The review looked at the shipyard's overall plan and progress, as well as reviewing each functional area, and examining integration of the shipyard's plan with the COSP. A detailed report of findings and recommendations to the Shipyard Commander was the result of each review. The COSP management plan calls for periodic on-site reviews to be conducted at each shipyard in order to continue effective implementation and to sustain the focus on continuous improvement and TQL.

On 16-18 January 91, the initial meeting of the COSP Advisory Group was conducted. The purpose of this meeting was to review over 80 COSP Issue Papers which had been developed to recommend changes to the COSP. Subsequently, the shipyard BOD also met in January 1991 to act on the COSP Advisory Group recommendations. The resulting changes to the COSP demonstrated the commitment to continuous improvement.

The manner in which Shipyard Commanders and NAVSEA 07 focus attention of their employees on the COSP will to a great degree determine the success of the improvement initiative. In the current period of workload reduction and downsizing, it will be particularly difficult to achieve the COSP objectives without a total team effort. A total commitment of ownership must be taken by all line management. It is especially important for managers to understand the mutual commitment to the COSP's initiatives, goals, and objectives, and be visible participants in implementing change and overcoming obstacles.

There are three fundamental approaches to successful accomplishment of the COSP: (1) Back to Basics, (2) TQL, and (3) New Tools. In the "back to basics" category, people must learn their jobs and work harder and smarter. This is especially important in planning and scheduling work. All employees must understand the totality of their work and all of its relationships and dynamics. This category also includes some fundamental approaches to work performance and management, such as use of project managers. It is necessary for shipyards to have both project management for product focus and functional management for process excellence in order to succeed in this extremely complex business. A natural partnership with "back to basics" is Total Quality Leadership (TQL). The focus of TQL is to manage and continually improve the processes that produce the products. Here, production functional line managers must be involved with their processes and tune in to good ideas from all sources. Processes can not be allowed to run on automatic, or the "way we've always done it". The application of TQL principles and practices, including employee involvement is the "fabric" for implementing the COSP. Finally, the shipyards and SEA 07 are developing and implementing new tools to do work more efficiently and effectively, such as the Advanced Industrial Management (AIM) program and a comprehensive effort to modernize the Inside Machine Shops.

The bottom line in COSP implementation is to demonstrate actual improvements in the products delivered to the customer. To that end, a corporate shipyard performance measurement system has been established. This system, called the Shipyard Performance Quarterly Review (SPQR), measures the significant "top level" indicators and attributes of shipyard performance, which are directly related to the COSP goals and objectives and to the DMRD savings goals. A reporting and monitoring process to collect and review the needed information and data has also been established. The SPQR will provide the yardstick to measure the improved performance (i.e., cost, schedule, quality, safety, and financial) results from TQL and COSP implementation.

SUMMARY/FUTURE

The naval shipyards, today as in years gone by, face serious challenges with force structure reductions and severe budgetary pressures. History confirms that these conditions are unlikely to abate. The COSP is the corporate strategy for meeting these challenges in a united and focused manner. The shipyard community recognizes the importance of meeting the goals and objectives of the COSP. Failure to achieve the required efficiency and productivity improvements will severely affect fleet readiness, putting in jeopardy, once again, the survival of naval shipyards. A sense of urgency and commitment to this effort now exists at all levels of NAVSEA and the shipyards.

Continuous improvement in our industrial operations is required. Through the COSP, institutionalization of proven success to realize long term recovery is possible. The recent period of overload, in workload, and in the flood of management assessments and improvement initiatives, diffused management focus, effectiveness, and discipline. Management attention is now directed toward the major functional areas which form the core of the COSP efficiency and productivity improvement strategy. The bottom line as Admiral Kelso said when speaking to senior shipyard managers, "And the only way to silence the critics, and we have a lot of critics, is to become competitive with any shipyard, public or private. ... If we lose it, we won't regain it very easily."

The shipyard community has in hand the road map to success; the Corporate Operations Strategy and Plan. By relentless attention to the plan's key issues – cost and schedule performance, technical excellence and human resource strategy and environmental compliance – NAVSEA 07 and the naval shipyards will achieve continuous improvement. Total Quality Leadership, the naval shipyard's driving force for improvement, requires the vision and goals of the plan if it is to become a reality.

Bibliography

The Naval Industrial Improvement Program - Initiatives: 1985-1989, October 1989

Ship Depot Maintenance Study - January 1989

Appendix A

1A. SCHEDULE PERFORMANCE

1A.01 Institute Integrated Shipyard Scheduling
1 A.02 Strengthen Talent of Scheduling Personnel
1 A.03 Match Workload and Shop Trade Skills
1 A.04 Strengthen Accountability of Shipyard Senior and Middle Managers in Schedule Adherence

1B. DIRECT LABOR COST PERFORMANCE

1B.01 Roll out Cost Estimating/Execution Task
1B.02 Active and Proper Participation in Excess Labor Shop
1B.03 Improve Workforce workload Balancing
1B.04 Implementation of Supervisor's Desk
1B.05 Resolve Impact of First Line Supervision
1B.06 Require Second Level Supervisor to Plan Resource Utilization Every Week and Modify Daily
1B.07 Uniform Cost Schedule Control System (C/SCS) Application.
1B.08 Review Cost of Direct Contractual Service
1B.09 Implement Project Management
1B.10 Implement Functional Work Teams and Codes
1B.11 Roll Out NIIP Proof of Concept Lessons Learned to All NSY's and Assess Follow-on MIS
1B.12 Implement Delay Code Reporting
1B.13 Control of Naval Shipyard Overtime

1C. OVERHEAD COST PERFORMANCE

1 C.01 Follow-up Analysis of Overhead Reduction Review
1C.02 Gain Control of FECA Costs
1C.03 Improve Management of and Implement C/SCS for Overhead
1C.04 Address Policies/Regulations that Impact Management of Overhead
1C.05 Eliminate Unused Capacity

1D. MATERIAL COST PERFORMANCE

1D.01 Improve the Material Requirements Determination Process
-Material Planning Group
-Contingency Material
-C/SCS Material Module
1D.02 Develop Material Requirements (MR) module for SYMIS
1D.03 Develop Long Term MVIS Automated Sourcing
1D.04 Expand Short Term Material Visibility Information System (MVIS) to Include Ships Parts Control Center SPCC System
1D.05 Increase/Improve Material Management Training
1D.06 Update Industrial Material Policies and Goals
1D.07 Roll out Statistical Physical Inventory Tool for Improving Inventory Reliability (SPITFIRE) Inventory Accuracy Program
1D.08 Expand Material Distribution Initiatives (Kitting, Stagin, Trigger Delivery, Material Control Centers, Scrap Metal and Excess Material Recovery Programs)
1D.09 Change Policy to Improve Return on Excess (Navy Stock Fund (NSF) Credit, Disposa l Policy)
1D.10 Incorporate Lessons Learned from Proof of Concept
1D.11 Plan for Future ADP and Material Distribution Needs

1E. IMPROVED CAPITAL PLANT MANAGEMENT

1E.01 Implement NAVSEA Corporate Capital Asset Management Plan
1E.02 Modernization of Shop 31 Practices and Procedures
1E.03 Develop Implementation Plan for Local and Wide Area Networks at all Shipyards Supportive of IRM Strategy and Initiatives
1E.04 Raise Minor MILCON Threshold from 200K to 500K
1E.05 Develop Utility Efficiency Plan

2A. TECHNICAL EXCELLENCE

2A.0 Implement the Advanced Industrial Management (AIM) Program
2A.02 Accelerate Issue of All Steam and Electric Plant Quality Improvement Program and SUBSAFE Work Documents
2A.03 Develop and Implement a Corporate Information Resources Management Plan which Includes Strategies for AIM
2A.04 Project Five Year Need for Engineers, Scientists and Technicians
- Develop Recruiting and Training Plan to Support this Need
2A.05 Implement Planning and Estimating (P&E) Skills Training
2A.06 Implement Standard Production Trade Skill and Job Skill Training
2A.07 Implement Trade Proficiency Testing
2A.08 Consolidate and Intensify Reviews of Cumbersome Work Practices
2A.09 Develop Simple, User-Friendly Technical Work Documents
2A.10 Establish Centers of Excellence

2B. SAFETY ENHANCEMENT

2B.01 Develop Occupational Safety and Health Program Improvement Plan (OSHPIP)

2C. HUMAN RESOURCE STRATEGY

2C.01 Implement Industrial Management Development and Training Program for NSY Supervisors and Managers
2C.02 Implement Flexible Employment Strategies for NSY Manning Requirements
2C.03 Reestablish Fast Track Waiver System at Secretariat Level to Provide Rapid Resolution of Field Activity Personnel Concerns
2C.04 Enforce Accountability of Corporate Goals Performance Appraisals of Senior Shipyard and Headquarters Personnel
2C.05 Develop a Five Year Plan to Accommodate the Projected Shift of Work Force Demographic

3A. ENVIRONMENTAL COMPLIANCE

3A.01 Develop Environmental Compliance Plans Incorporating DOD, Navy, Federal, State and Local Requirements
3A.02 Develop Training Plans Incorporating Environmental Requirements
3A.03 Identify Hazardous Waste Streams and Establish a Coordinating Group to Minimize Generation of Hazardous Waste By-Products in the Industrial Process

IMPROVING THE SHIP DESIGN, ACQUISITION AND CONSTRUCTION PROCESS

J. Christopher (Kit) Ryan
Project Manager
Ship Design Group
(SEA 50D)
Naval Sea Systems Command

Otto P. Jons
Vice President of Engineering
Advanced Marine Enterprises, Inc.

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ABSTRACT

In the Spring of 1990, the NAVSEA Chief Engineer initiated a project to improve the design, acquisition and construction (DAC) of U.S. Navy ships. The project's objectives are to reduce the time and cost of acquiring and operating Navy ships while improving their quality. Unlike previous studies on the subject, the project utilizes a rigorous process analysis approach and attempts to use quantitative measures as the basis for recommending improvements.

The paper is, of necessity, a status report on the progress of this project. Topics covered include: the DAC process; a look at the current state of ship acquisition time, cost, and quality; the methodology for process improvements; and early findings.

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NOTATIONS/DEFINITIONS/ ABBREVIATIONS

ACAT	Acquisition Category
ASN (RD&A)	Assistant Secretary of the Navy (Research, Development and Acquisition)
BCC	Basic Construction/Conversion Cost
CD	Contract Design
CNO	Chief of Naval Operations
COR	Circular of Requirements
DAC	Design, Acquisition and Construction (abbreviation used only for convenience in preparing this paper)
DOD	Department of Defense
DTRC	David Taylor Research Center
ESG	Executive Steering Group
GFE	Government Furnished Equipment
HME	Hull, Mechanical & Electrical
INSURV	Board of Inspection and Survey
MTTR	Mean Time To Repair
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense

PD	Preliminary Design
PPBS	Planning, Programming and Budgeting System
PSA	Post Shakedown Availability
RFP	Request for Proposal
SCN	Ship Construction, Navy
SHIPACS	Naval Ship Acquisition Study
SPAWAR	Space & Naval Warfare Systems Command
SPC	Statistical Process Control
TOR	Tentative Operational Requirements
TQM	Total Quality Management

PREFACE

This paper is called a progress report because, as of this writing, there are several months to go in the first major phase of the project. If this truly is the first step in a program of continuous process improvement, then all such papers in the future must also be considered progress reports.

BACKGROUND

The process of acquiring ships for the U.S. Navy is unique within the Department of Defense (DOD). Navy ships are bought in small quantities, have long development cycles, and are extremely costly on an individual basis, precluding conventional "fly before you buy" approaches used for the procurement of most other major systems. The first ship of a new Class must already be a fully operational weapons system. This combination of circumstances results in the ship acquisition process following a modified approval in fulfilling the DOD directives and has led to the evolution of a complex process for subdividing and performing the functions inherent in the acquisition of our ships. The definition of that process has been primarily the responsibility of the Navy. Regrettably, it is neither well documented nor understood by many of those involved.

Because of the large amounts of money invested in defense systems acquisition, it has been subjected to close public, congressional and DOD scrutiny, as evidenced by the large number of studies devoted to analyzing and improving the acquisition process. Table 1 provides a summary of a dozen

TABLE 1

STUDIES RELATING TO SHIP ACQUISITION - OVERVIEW

Date	Name of Study	For	Conducted by	Purpose and Scope
1954	Gates Committee	SECNAV	Navy in-house committee	Review of organizational structure of the Department of the Navy to identify overlapping or duplicative functions, problems and difficulties.
1959	Franke Board	SECNAV	Navy in-house committee	Review of organization of the Navy in view of DOD Reorganization Act of 1958 and technological advances since the Gates report.
1962	Dillon Review	SECNAV	The in-house representatives and consultants	Comprehensive review of entire Navy organization; in-depth review of functions and operations down to and within bureaus and offices.
1966	Shea Report	SECNAV	National Academy of Sciences	Critical review of the procedures associated with the formulation of ship characteristics, determination of design, and systems integration of hull, machinery, weapons, and other equipment.
1967	SHIPACS	SECNAV	Navy in-house Committee	Verified and examined in detail the key problems identified by the National Academy of Sciences Shipbuilding Study Group.
1969	SCN Pricing and Cost Control Study	SECNAV	NAVMAT	Identify improvements in the shipbuilding and conversion management system needed to ensure that programmed ships could be acquired within the limits of the Shipbuilding and Conversion, Navy (SCN) appropriation.
1969	Blue Ribbon Panel Report	U.S. President	Panel appointed by Richard Nixon	Study and report on the organization and management of the Department of Defense.
1975	NMARC	SECNAV	Navy and Marine Corps Acquisition Review Committee	Assess the organization, management, staffing, and procedures used by the Department of the Navy in developing and producing major weapon systems.
1978	Naval Ship Procurement Process Study (NSPPS)	ASN (M, RA&L)	Committee appointed by ASN	Examine problems areas which had emerged between the Navy and the shipbuilding industry and were relevant to the massive and controversial shipbuilding claims presented to the Navy in the 1970s.
1979-1981	NAVSEA Ship Acquisition Policy Positions	COMNAVSEA	NAVSEA in-house team	Review and analysis of the NSPPS conclusions to determine where policy or procedural improvements could be made and how they could be implemented.
1979-	Workshop on NAVSEA Engineering	COMNAVSEA	MIT Center for Advanced Engineering Study and Consultants	Review the demands on NAVSEA's engineering force in light of personnel ceilings and recommend more effective use of talent.
1982	Ship Design at NAVSEA	COMNAVSEA	NAVSEA In-House Team (Fee, Gale, Lankford, Johnson)	Defined NAVSEA ship design strategy for the 1980's, incl. design efficiency, personnel effectiveness, effective use of of external resources.

major studies conducted in the last forty years dealing just with ship acquisition. Many other studies have also been done on ship design or DOD acquisitions. These studies should be of interest to more than just the history buffs; they are often surprisingly relevant today as evidenced by the following excerpts:

- "Responsibilities for decision making on ship requirements and ship characteristics [are] dispersed through a large number of organizations within the Department of the Navy"
- "The application of formal DOD RDT&E procedures to ships [is] not understood even within OSD."
- "Major causes of deficiencies are attributable to:
  - Inadequate planning for the early, firm definition of ships
  - Failure always to balance program decisions with their cost impacts"

The sources of these statements, which could well have been made today, are the 1966 Shea Report, the 1967 SHIPACS Study and the 1969 SCN Study, respectively.

The ship acquisition process appears to have changed little over the last 30 years, with the exception of Total Package Procurement in the mid-60's. However, the environment and the execution of the process have, in fact, changed significantly over that period: design time has increased, ship complexity has increased, ship construction practices have changed to reflect more efficient methods, technology has been changing at an increasing rate, contracting practices have been altered, budget cuts have occurred, etc. Each of these factors has been individually "spliced" into the existing process without specific consideration of its impact on the overall process. While the U.S. Navy and its supporting industrial base deliver highly capable ships to the fleet, the need for a continuing search for improvement is evident.

PROJECT INITIATION

The NAVSEA Chief Engineer has initiated an effort to improve the performance of the Naval ship design, acquisition, and construction (DAC) process. The project was inaugurated at a Performance Improvement Planning Workshop 27-29 June 1990 in Richmond VA ("Richmond Retreat"), which addressed the broad spectrum of issues surrounding ship acquisition. Wide ranging attendance by representatives of the Navy and industry ensured the identification of the full spectrum of areas for subsequent investigation and action. Literally dozens of "roadblocks" to process improvement were compiled and specific objectives and actions were defined at the Workshop. A report from the Workshop documents these results. [1]

The Richmond Workshop was held to:

- provide overall direction for improvement efforts;
- get advice on "where to look first" based on the expertise of the Navy and industry representatives; and
- develop momentum and support for the subsequent efforts.

As stated by the NAVSEA Chief Engineer, the overall objective of the Naval Ship DAC Improvement Project (the "Project") is:

"To identify the critical actions necessary to improve the quality of future ship designs (i.e. meeting customer's requirements) to reduce ship construction costs, life cycle costs and to reduce the time required from establishment of requirements to delivery of the lead ship."

Subsequent to the Workshop, an Executive Steering Group (ESG) was formed to provide continuing project oversight. The ESG includes members from all those organizations which are in-house "stake-holders" in the outcome: OPNAV, ASN(RD&A), NAVSEA, NAVAIR, and SPAWAR. The ESG restricted project participation to Government personnel because of the difficulties in establishing official advisory groups with industry. The ESG has met quarterly to review progress and provide additional guidance. The schedule calls for presenting the results in draft form at a second workshop to be held in May 1991 to obtain government and industry reactions and further input before finalization.

PROCESS IMPROVEMENT TEAMS

The success of the project depends on extensive knowledge of the DAC process coupled with significant amounts of analysis effort. We recognized early-on that teaming was the best method to accomplish this by bringing expertise from the wide range of disciplines involved.

The strategy was to divide the overall improvement effort into meaningful parts that could be worked on by relatively independent teams. Teams were organized along the major divisions within the DAC process as depicted in figure 1. The main sequence of product (ship) development starts with Requirements Setting, followed by Engineering, then Construction, and finally service life Operations and Support. Overseeing all of this effort is the Program Management function. Supporting all efforts is the Resource function. But ship development itself was only part of the story, particularly for combatant ships; combat system and,

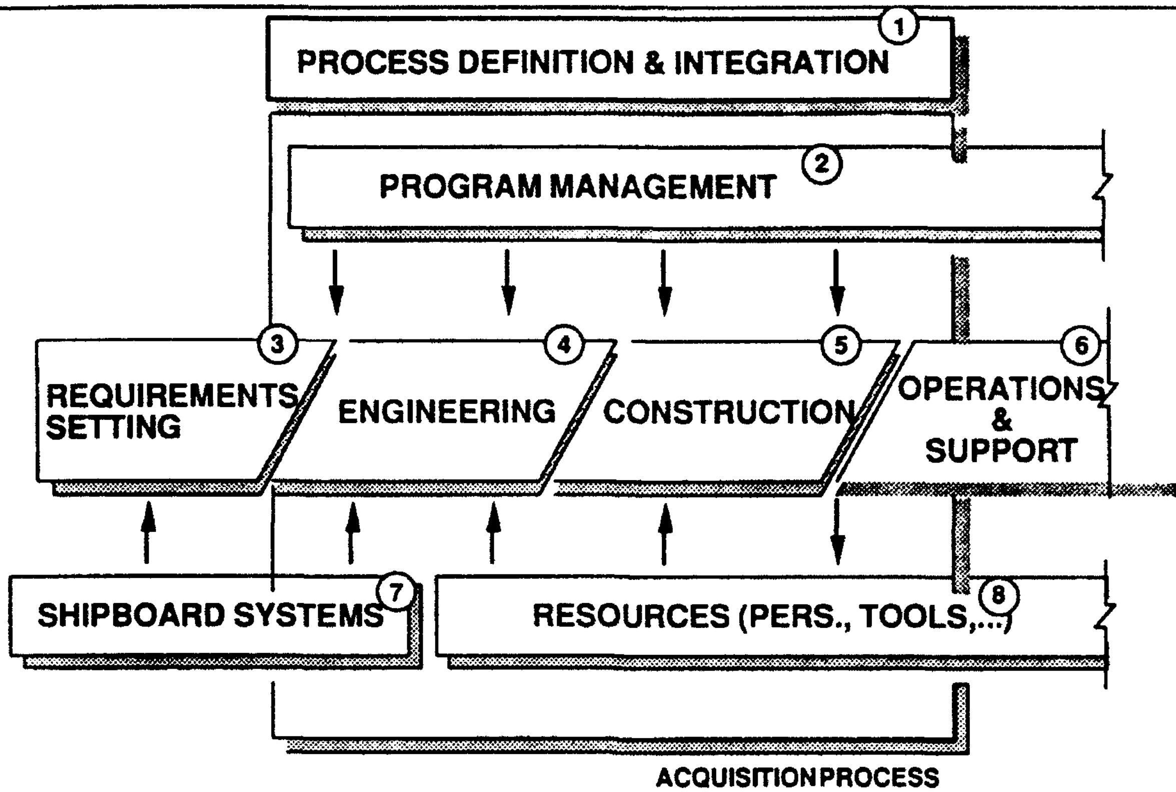


Figure 1. Team Organization

to some degree, HME equipments have a major impact on acquisition time, cost and quality and are not well represented by the main ship development sequence. Shipboard systems development was, therefore, included as an essential and distinct activity integral with overall ship acquisition and service life.

These seven teams were capable of addressing all aspects of the DAC process. However, many issues cross over the nominal boundary of a given team's area of responsibility. Thus, the Process Definition Team was established to take on the integration of the other team activities and ensure consistency throughout the effort. This Process Definition Team is made up of the Team Leaders from the other seven teams. Figure 1 shows that we numbered the teams 1 through 8 for convenient referencing.

Team membership was drawn from NAVSEA, NAVAIR, SPAWAR, DTRC and academia with well over 60 people involved on a regular part-time basis. For the Construction Team, representing a function which is effectively all within industry, individuals with long-term working relationships with industry or prior work experience in industry were specifically included to ensure that the best available in-house expertise was employed.

In addition to the teams, the project has received support from a number of other Government sources, primarily in providing or analyzing data. In that respect, the effort truly represents the work of a substantial number of people; a team effort has been at the heart of this project since its inception. The ESG and team membership is shown in figure 2.

DISCUSSION OF APPROACH

A number of factors affected the approach and included recent developments in management theory, productivity improvements and quality awareness, as well as lessons learned from past experience with ship acquisition programs and recommendations from prior studies to improve these programs. These factors included:

Recent Management Theories Aimed at Quality and Productivity Improvement

NAVSEA's process improvement initiative has been kicked-off at a time of increasing awareness that some of our competitors in the world have been doing things differently, and quite possibly better, and that our country's reputation for delivering quality products and services has been deteriorating. As a result, the eighties have seen a renewed focus on productivity improvement, customer-orientation and

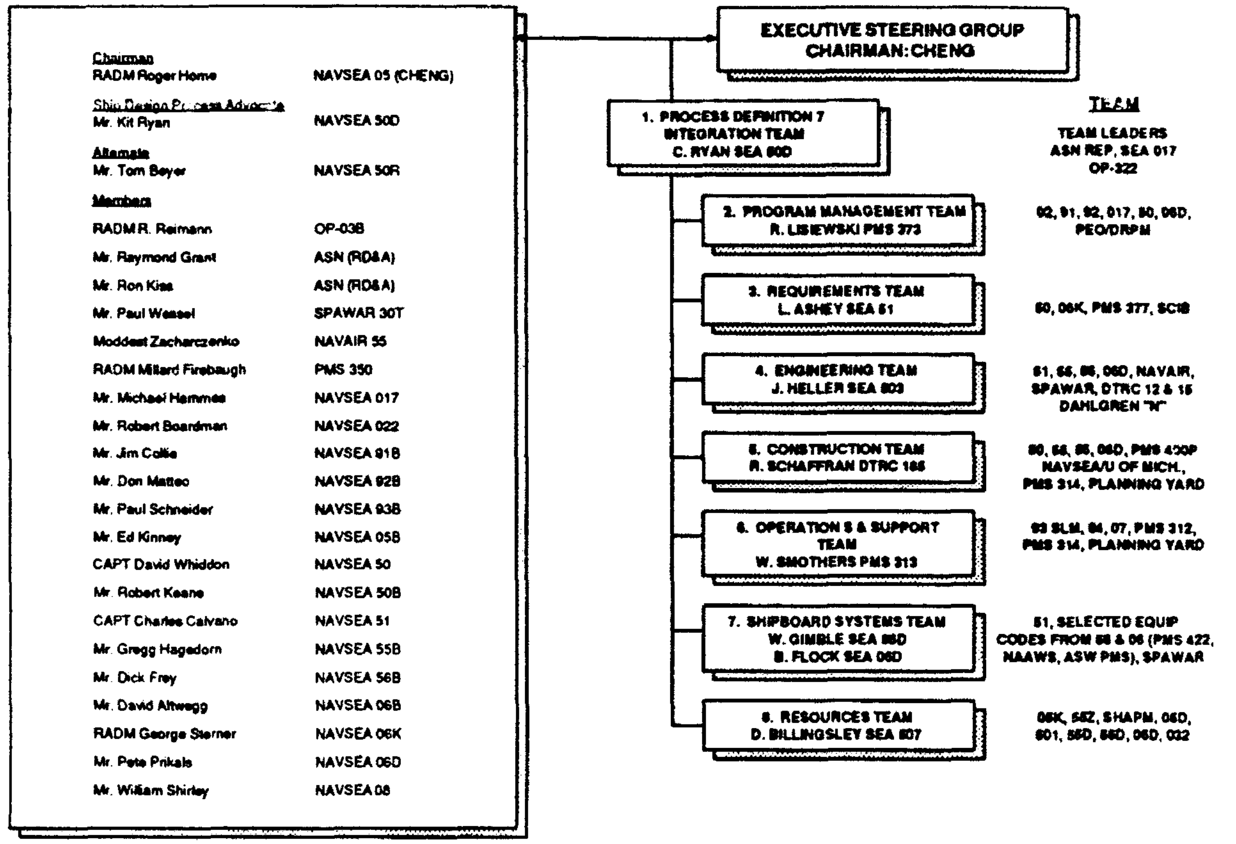


Figure 2. Executive Steering Group and Team Membership

quality. New management theories taught by W. Edwards Deming, M. Tribus, R. Crosby, J. Juran and many others are credited with truly remarkable successes, initially in Japan and, in the last decade, in this country as well. Our language has been "enriched" by acronyms such as TQM, QFD, SPC, etc. While some of these already have fallen into disfavor because of overuse, others are being created continually.

While not all aspects of TQM (Total Quality Management) are universally embraced, some are generally accepted as crucial to effective process improvement. The conduct of the Richmond Workshop, its attendance, the subsequent formation of the ESG and the Teams pursuing the initiative all serve as evidence that some of the above concepts were applied.

After analyzing these concepts, we found a wealth of ideas, yet, few ready-made answers. The issue of "quality" turned out to be particularly challenging.

Quality - What is it?

The term quality, so easily treated in casual conversation, becomes elusive as soon as attempts are made to measure it. Numerous definitions of quality have been proposed, [2], [3], [4]. Yet, not one identifies (or even implies) how to measure it.

When thinking about the quality of a Navy ship, the following may come to mind:

- Quality as the ability to achieve performance requirements over time
- Quality as low cost maintenance
- Quality as a safe ship
- Quality as freedom from unknown problems
- Quality as easily found problems and quickly restored systems
- Quality as easily learned operation and maintenance
- Quality as survival in combat
- Quality as a good living and working environment

Some of the above are merely general statements of performance requirements. All serve to illustrate that it is very difficult to define precisely, correctly and in an unambiguous manner all requirements stated by the customer. Furthermore, it becomes clear that it is very difficult to relate the actions of individual participants in the process to their impact on these high-level quality concepts which tend to apply to the final product, the ship.

To resolve the quandary, we ended up formulating the following definition:

QUALITY - Conformance to Customer Requirements *and Expectations*

The term "*and expectations*", we believe, is of great significance. It implies two things. First, quality is "in the eye of the beholder" (the customer); an agreement on a desired level of quality will often require a dialogue between customer and producer/supplier to enable the latter (NAVSEA) to fully understand what it is the customer (OPNAV) really wants. Secondly, the question of *who the customer really is* becomes of critical importance, as further discussed under "Process Abstraction" below.

For now, we shall be content to conclude that a quality product meets the customer's requirements and expectations fully, or within an acceptable margin.

Ideally, quality is expressed (and measured) in the form of *a performance requirement with an acceptable deviation* from that level. Unfortunately, in the real world, customer requirements and expectations are often hard to quantify and frequently involve intangibles; the term "Voice of The Customer" has been used in the literature to convey the recognition that his voice often requires interpretation. The now widely used technique of Quality Function Deployment (QFD) has been devised specifically to aid in interpretation or translation of this voice.

Lessons Learned From Prior Studies Aimed at Improving the Process

We have tried hard to avoid the trap so well communicated by Santayana ("Those who cannot remember the past are condemned to repeat it.") At the outset, a concerted effort was launched to create a reference library of significant reports, studies, papers, and articles related to the design, acquisition and construction of ships. This reference library, consists of over 125 documents and is available to all team members. All the documents represented in the database were reviewed. Abstracts, conclusions and recommendations from each document were entered into a computer-based information management system and related to a series of keywords, including relevant designations of the eight NAVSEA teams. The keyword selections include generally used acquisition, design and construction terminology. The association of the selected keywords was based on relevance to the charter of each of the teams. The resulting database is an information source which offers a quick search capability for access to some of the most important published and unpublished work in the ship design, acquisition and construction areas.

Time/Cost/Quality: Product vs. Process

This final factor had a profound impact on our approach. Specifically, if the objective is to reduce the cost of the ship, that is, the *product* then the solution is unlikely to be given by simply spending less on all individual phases of the *process*. Similarly, if the objective is to reduce the time to deliver the ship, then the solution is not necessarily to spend less time on all individual phases of the process. Moreover, spending less time on the critical early phases of the process will probably have a detrimental effect on *product* cost and quality, and maybe even on the time to deliver the ship. It is in these phases when the major decisions affecting product quality and cost are made.

In summary, time, cost and quality cannot be dealt with separately. Furthermore, they can be addressed meaningfully only in the context of the total process and its impact on the end product, the ship.

APPROACH: STEP-BY-STEP

The approach consisted of five steps as shown in figure 3. The first two steps, are straightforward: before you can address improvement in a meaningful manner you must know where you are, and how you are currently doing. With this knowledge, a baseline can be established for further analysis of improvement options and for the identification of bottlenecks. The subsequent steps 3 through 6, were less obvious and, in fact, are part of what we feel are advances in process improvement techniques. The steps, in sequence, are:

STEP 1: PROCESS DEFINITION AND DOCUMENTATION

The current process is defined in flow chart/time line fashion and documented to reach a common understanding of how we currently do business.

STEP 2: PERFORMANCE ANALYSIS

How well the current process actually works was determined by quantitative measurement. Initially, heavy emphasis was placed on the three fundamental process performance attributes, i.e., the time (to be reduced), the cost (to be reduced) and quality (to be improved) of the product. These measures can apply to both the final

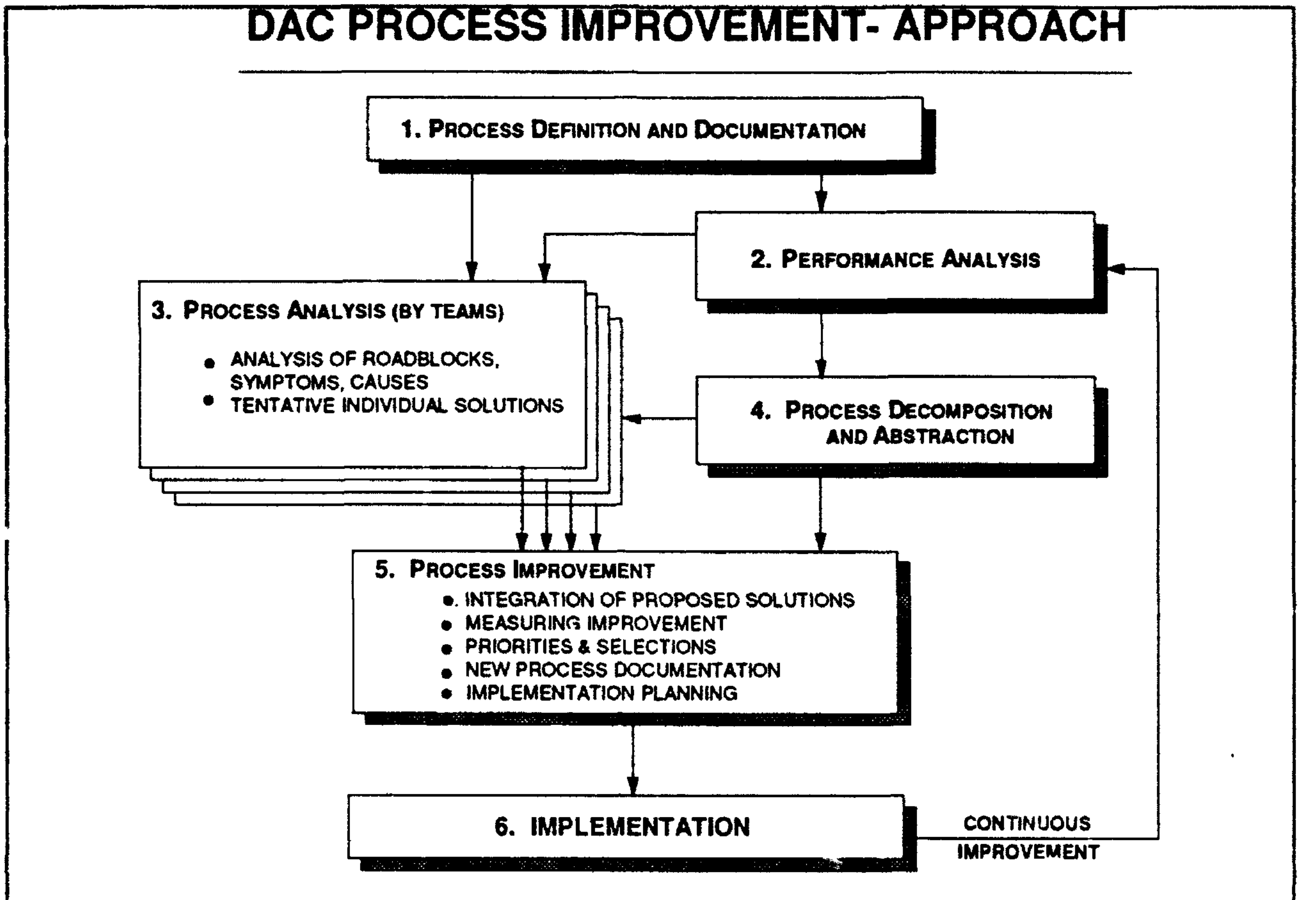


Figure 3. Approach to DAC Process Improvement

product, the ship, as well as interim products such as drawings produced during Contract Design. The objective was to establish hard information about our process for two purposes: 1) the subsequent analysis of the process, and 2) the future measurement of the affects of changes made to the process. The format for displaying "measures" are graphs or tables of values. Since they are quantitative, they can later be used both to evaluate the individual improvement proposals and to prioritize them for implementation on the basis of maximum payback.

STEP 3: PROCESS ANALYSIS

This step involved the search for individual candidates for improvement. Regarding time, as one example, the critical path through the process was identified, key events labelled and lost or non-productive time noted. In a similar manner, but less obviously, the contribution of each step in the process to ship cost and quality was evaluated. Time-, cost-, and quality-"drivers" were identified as well as "symptoms" and "causes". These factors correspond to the "roadblocks" identified at the Richmond Workshop. In short order, large numbers of apparent solutions to individual problems as well as ideas for improving certain aspects of the process were identified. Yet, the true impact of these ideas and their ultimate merit in light of their contribution to the end product's cost, quality and time still remained to be assessed.

STEP 4: PROCESS DECOMPOSITION AND ABSTRACTION

This step was added to deal with the need to establish a common understanding of the process by the full spectrum of disciplines involved. Finding ways of breaking down this complex process into manageable pieces without blurring crucial distinctions became mandatory for dealing effectively with the multitude of symptoms, causes, roadblocks and improvement proposals affecting virtually all aspects of the process. However, we were then left with a large number of process elements to be integrated. Some abstraction became necessary and involved the derivation of certain elements common to all processes. General improvement principles were derived which permitted us to deal with process interactions in a systematic manner. This step served to develop tools which were critical for the next step.

STEP 5: PROCESS IMPROVEMENT

This step involves the integration of those proposed roadblocks and solutions selected for implementation. The proposals developed for individual subprocesses must be linked in a scheme which provides completeness, continuity, no overlap, and benefits for the final product, the ship. The payback as well as cost for implementation needs to be estimated so that the most promising proposals can be selected. Selection must be based on demonstration of payback which, in turn, cannot be established without measurements. Finally, the redefined process must be documented and implementation must be planned for.

STEP 6: IMPLEMENTATION

This last step is listed for the sake of completeness. There is little that can be discussed at this point.

RESULTS TO DATE

STEP 1. PROCESS DEFINITION AND DOCUMENTATION

Perhaps the first real insight into process improvement occurred early in the project when it became clear that the DAC process was not viewed the same by all team participants. We developed a timeline style breakdown of the process which encompasses over 130 subprocesses. It could not be included here due to publishing limitations but will be made available in a future report from the project. The chart included essential information on *who* did *what when* and what *major documents* were involved for an ACAT 1D acquisition, perceived as the most complex category. Yet, even with that many subprocesses, the chart necessarily represents a very simplified view of the whole process. As a point of reference, the Preliminary and Contract Design process that existed in the early 70's was documented for use in ongoing computer supported design efforts; 12 three-ring binders were required just to hold the flow charts. Clearly, the total DAC process encompasses thousands of individual subprocesses and is beyond the scope of this project.

Several insights into the DAC process became evident:

- The current acquisition process is commonly depicted as shown in figure 4 which was derived from [5]. It follows DOD instructions only in general terms. Specifically: Milestone II (Concept Validation) is generally a pro-forma milestone since technical feasibility is rarely an issue for ships and the emphasis is placed instead on programmatic and funding issues; and Milestone IIIa (Low Rate Initial Production) is almost never utilized. Additionally, up until the most recent acquisitions of last year, Milestone 0 (Program Initiation) took place at OPNAV initiative and did not involve DOD.

- The full timeline for ship acquisition actually starts before Milestone 0 in at least three ways: combat system equipment is required to be developed well before the ship requirements are determined but have a major limiting effect on available ship options; the ship TOR itself must evolve prior to its emergence at Milestone 0; and an SCN budget "wedge" is inserted in the Six Year Defense Plan.

- At the other end of the timeline, the ship acquisition cannot be considered 100% complete at delivery by the shipbuilder. It is not until after the shakedown cruise and PSA that it is a deployable fleet asset.

- The process is not uniformly understood as evidenced by our project's difficulty in reaching consensus on the process flow chart.

- The process is often inconsistently followed. While general DOD guidance permits tailoring the process to the specific acquisition, the proliferation of acquisition strategies (CORs, mod repeats, variants, flights) further adds to the lack of understanding and difficulty of applying lessons learned from previous projects.

STEP 2. PERFORMANCE ANALYSIS

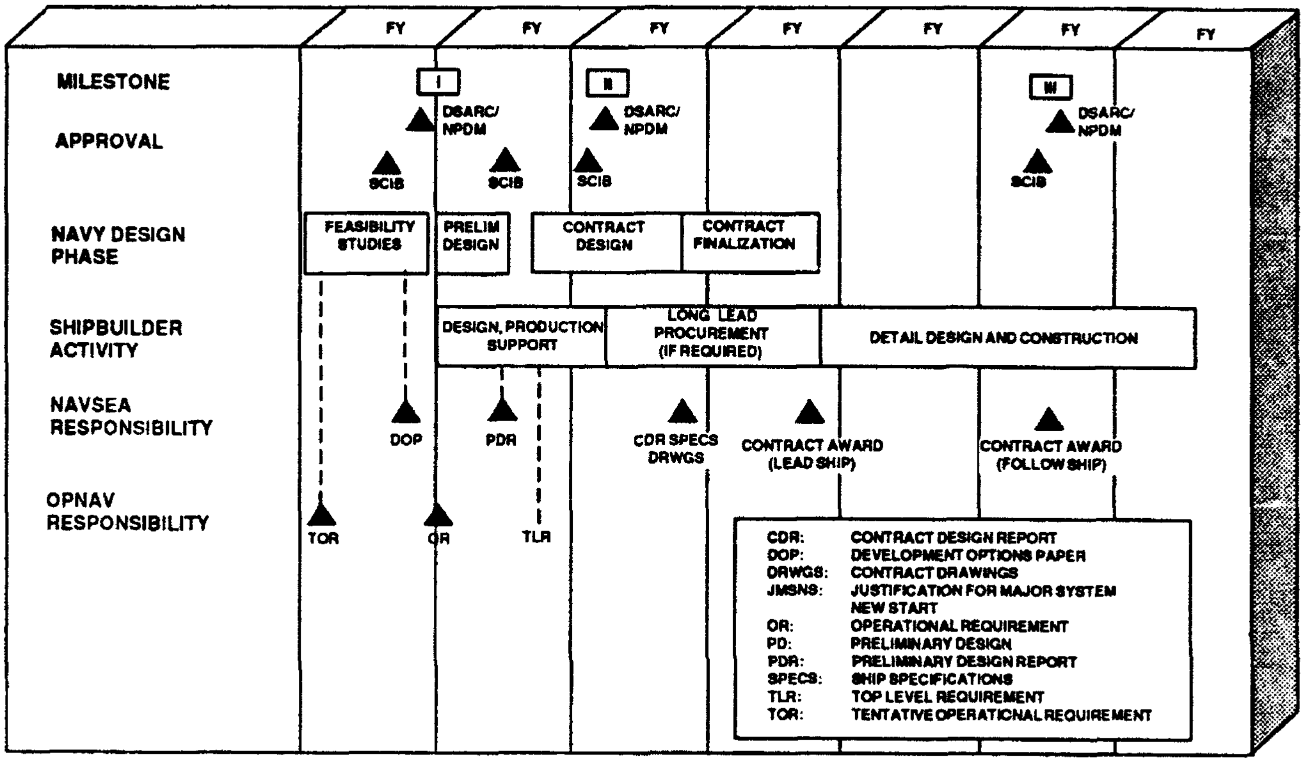
The current DAC process obviously works. But the real question is how well does it accomplish the function of producing quality ships for the fleet? Objective measures were developed to quantify some of the process characteristics to establish a baseline for further evaluation of improvement possibilities. For the time being time, cost and quality measures will be discussed separately. At this point in our analysis, we are looking solely at measures pertaining to the ultimate product, the ship, rather than intermediate products of the process.

TIME

Acquisition time trends for Navy ships have been grouped into combatants and non-combatants as shown in figures 5 and 6. The figures also show trends for individual DAC phases as well, namely: time from the start of Feasibility Studies (roughly corresponding to the beginning of requirements setting) through Contract Design; through award; and through actual ship delivery. Time through PSA, not shown, has similar trends. The time in months is shown plotted against the year in which Feasibility Studies were initiated.

With so few data points, one must be careful about drawing specific conclusions. Never-the-less, delivery trends for

NAVAL SHIP ACQUISITION PROCESS



NOTE: DESIGN PHASE LENGTHS SHOWN ARE TYPICAL OR RECENT EXPERIENCE. THEY WILL VARY FOR SPECIFIC DESIGNS.

DOD ACQUISITION PHASES AND MILESTONES

MILESTONE 0	Approval or disapproval of a mission need and entry into the concept exploration/definition phase.
MILESTONE I	Approval or disapproval to proceed into the concept demonstration/validation phase.
MILESTONE II	Approval or disapproval to proceed into the full-scale development phase and, as appropriate, low rate initial production
MILESTONE III	Approval or disapproval to proceed into the full - rate production and initial deployment phase. Initial deployment also marks the beginning of the operations support phase.

Figure 4. DAC Process and DOD Acquisiton Milestones

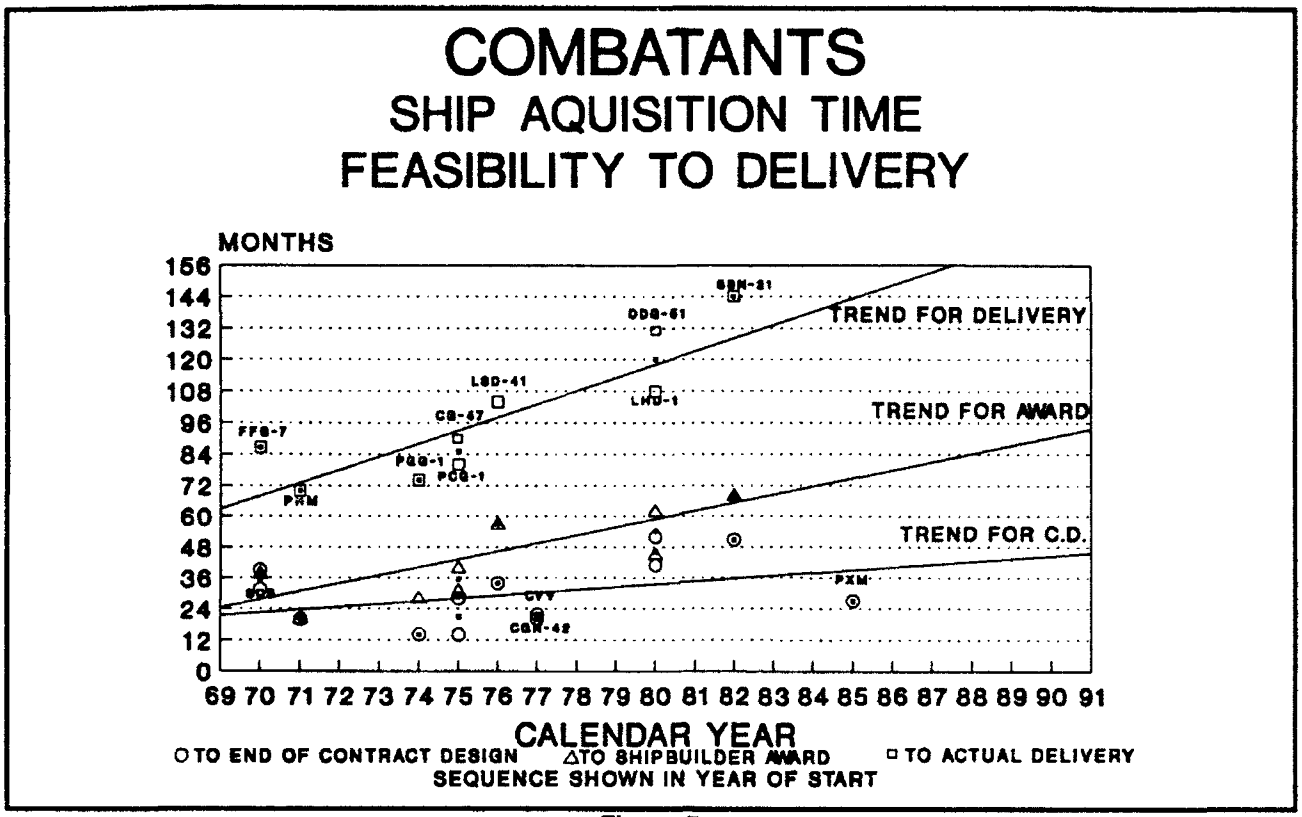


Figure 5

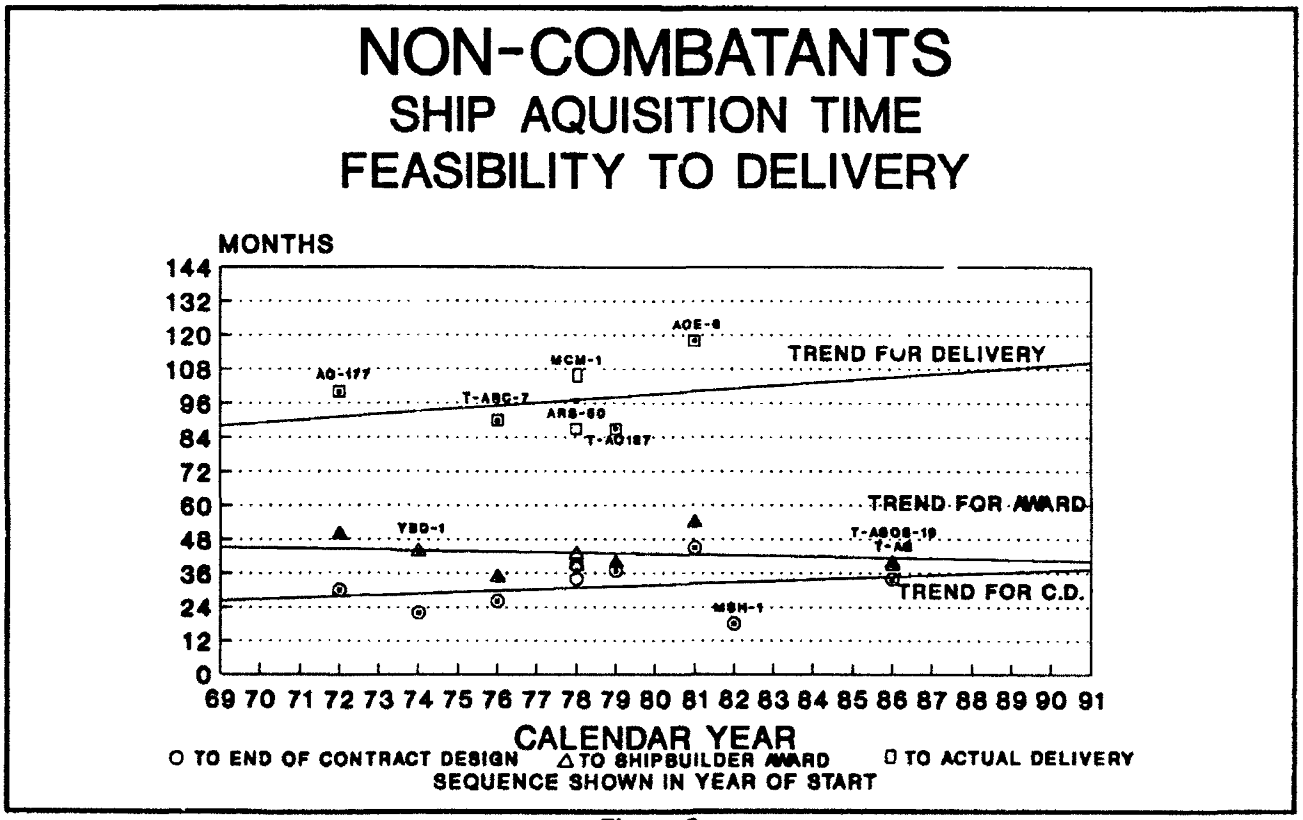


Figure 6

both types of ships are clearly increasing, with combatants more noticeably so. This is also true of the Navy portion of the design time through Contract Design. Non-combatants seem to be holding steady on award time despite increased design time.

Looking further into this, it is not surprising that design time is increasing, given the dramatic increases in the man-days spent on recent designs as shown in figure 7. This plot extends a similar one in Dr. Johnson's paper, [6] by adding ships designed since 1981. The effort (man days) expended has increased much faster than the calendar time for performing the design.

Despite the trends, in absolute terms, the overall time performance for acquisition of lead ships actually compares favorably to that for other weapons systems. Larry Wellman, David Taylor Research Center, has done a detailed look at the time for other acquisitions and provided the following results:

Lead ship acquisition (combatant)	12 years
Typical weapons system (1st production item)	15 years
Time for "official" DOD acquisition	22 years

The official DOD time was estimated, based on meeting the specific requirements of *all* applicable laws and instructions, which number well into the hundreds.

COST

Cost data for Navy ships was accumulated in standard breakdowns for both acquisition and service life. Only acquisition cost is addressed in this section. The most commonly used acquisition cost number is called "end cost" and includes all SCN funding from contract award through ship delivery. It does not include: ship design funding; combat systems development funding; outfitting; PSA; special training or support facilities. Since these other costs can be significant, "end costs" should be looked at primarily for comparison purposes and not for their absolute value. Similar rules apply to DOD aircraft acquisitions to permit fair comparisons.

Combatant "end costs" are plotted in figure 8 with an assumed trend line indicated. So better comparisons can be made, these are *average* ship costs, not just lead ships, and have been normalized to FY90 dollars. The trend line indicates an average cost growth of 800% per ship in equivalent dollars over a 30 year period. While this may seem dramatic, it actually compares very favorably with the cost for U.S. military aircraft over the same period (aircraft cost data taken from [7]). The cost for 10 bombers was roughly the same as that of one combatant ship from 1962 to about

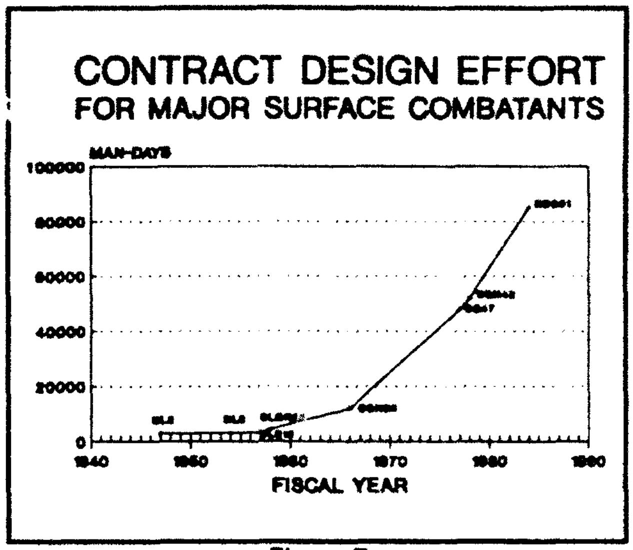


Figure 7

1970. At that juncture, aircraft costs went "sky high" and off the chart. This is well known, as the cost for one B-2 bomber has been quoted in the press as costing $600M-$800M or about the cost of one DDG 51. A commercial automobile trend line (10,000 station wagons) has been added to the chart as an additional reference, showing a mere increase by a factor of two in constant dollars.

QUALITY

There are no generally accepted measures of quality for Navy ships. As discussed previously, quality measures are really the quantification of the differences in performance between what was expected by the customer and what was delivered to him. Those aspects of Navy ships that are increasingly referred to as "quality issues" are merely those ship performance values that don't *currently* meet the customer's expectations. As we enumerate this list, we

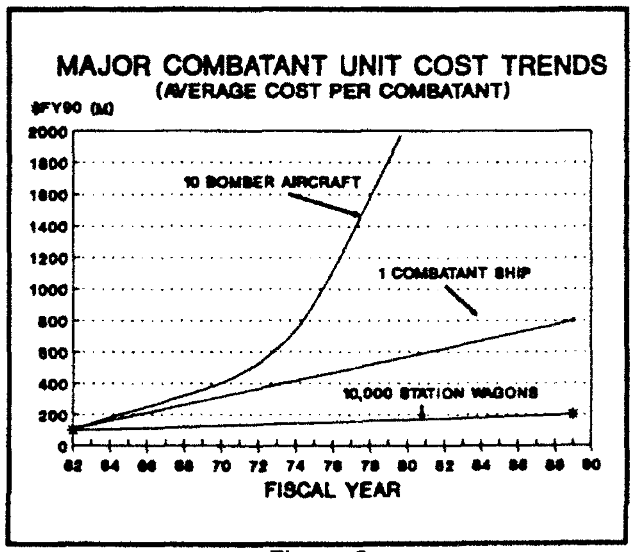


Figure 8

must realize that those items not on the list probably already meet or exceed the customer's expectations. They are still part of the overall quality picture because they also relate to total ship performance expectations in some manner.

A further wrinkle in addressing quality stems from defining *who is the customer*. Within any complex process, there are numerous customer and supplier relationships which must eventually be assessed, but even at the total ship level the customer is not clearly defined. In reality, there are many customers for the product of the DAC process, each with a unique set of expectations.

The list of quality issues which follows was based on significant weighting of the active fleet as the customer and utilizes data from INSURV annual reports to CNO among other sources:

QUALITY ISSUE (Samples)	MEASURES (Samples)
Mission performance over timeline	A_o for mission systems
Safety	# mishaps/year
Ease of learning to operate ship	Operations training cost
Ease of maintenance, incl. ease of learning to maintain ship	Maintenance and training cost MTTR
Survivability readiness	A_o for survivability systems
Living and working environment	Reenlistment rate

A_o is operational readiness and refers to the availability of systems over a specific timeline and scenario. It is based on real data that has been carefully scrutinized and evaluated using the TIGER computer model. It includes the effects of "logistical delay time", that is, the time lost when a spare part is not immediately available on board. MTTR is mean-time-to-repair, a measure of how long it takes to fix something after you discover it is broken.

To conclude this initial quantitative look, remember that the values on the charts are not in themselves good or bad but serve to establish a reference for future improvement initiatives. At this level of analysis, it is not possible to ascertain the "root causes" for why the curves or trends are as they are.

STEP 3. PROCESS ANALYSIS

With the performance of the overall DAC process established, the search for improvement opportunities began. Again using quantitative methods, the underlying reasons

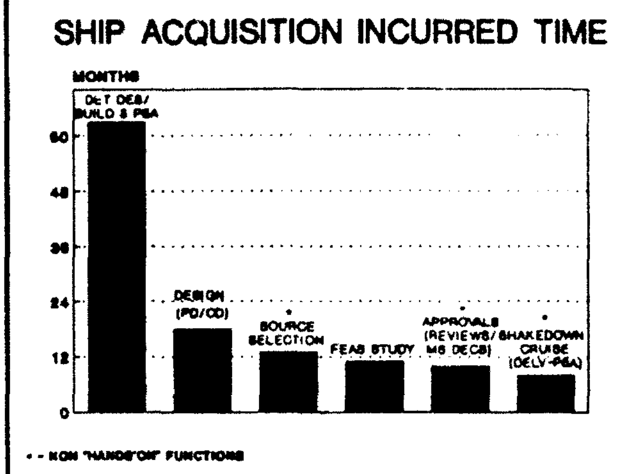


Figure 9

for the process behavior were analyzed and identified. Solution possibilities were proposed. In reality, insights are obtained sometimes by iterating this sequence, sometimes by reviewing past experience, sometimes by inspiration. Much of this work has been accomplished by the eight project teams and is still being assembled. What is presented is a sample of the assessments that are still underway.

Quantitative Analysis: Time

The first time analysis to be performed was to identify the "critical path" for ship acquisition, from Milestone 0 through PSA. In tabular form it looks like this for a typical combatant lead ship:

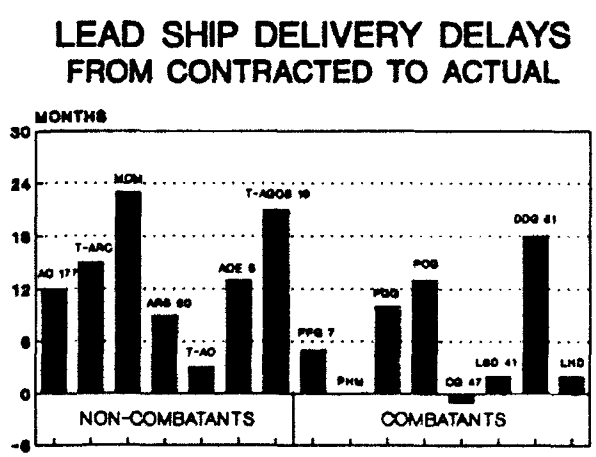


Figure 10

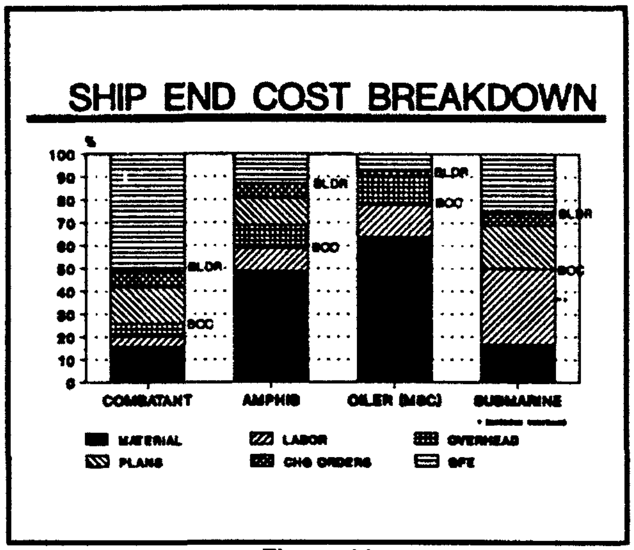


Figure 11

Event	Time (in months, average)
Milestone 0 (start acquisition)	
- Feasibility studies	11
- Reviews leading to Milestone I	5
Milestone I (select concept)	
- Preliminary Design(PD)	6
- Develop Class 'C' cost estimate	3
- Reviews between PD and CD	3
- Contract Design	11
- Reviews prior to RFP	3
- Source selection for lead ship	10
Award	
- Ship detail design & construction	60*
Delivery	
- Shakedown cruise	8
- Post Shakedown Availability (PSA)	3
Fleet Deployment	
Total acquisition time	123 months

* Including any delivery delays.

Analyzing the critical path for the distribution of time by function results in a Pareto chart shown in figure 9. It is no surprise that construction takes half the total time. What is a surprise is that the events which do *not* directly contribute to the development of the ship account for 25% of the total time. More specifically, source selection, reviews/approvals, estimating the Class 'C' cost (which takes place after the end of Preliminary Design) and the shakedown cruise require 29 months out of a typical acquisition cycle. (123 months)

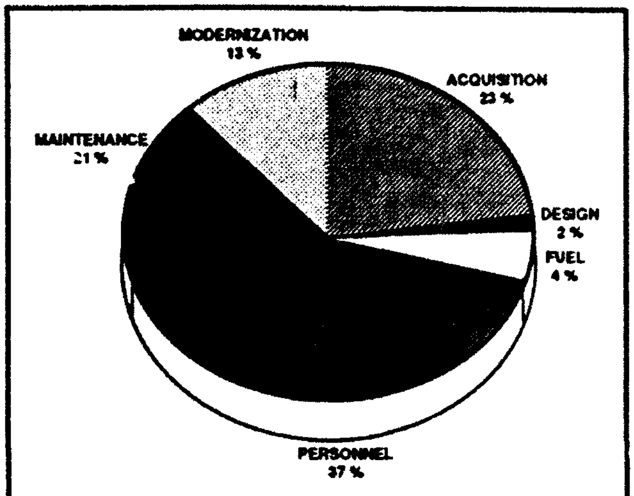


Figure 12. Life Cycle Cost Components for Typical Naval Ship

Digging a little deeper into the construction time, we see two things. PSA has been lumped with pre-delivery construction time to more accurately portray the total build time. The ship is not truly complete until the three-month PSA is done. A second feature of construction time is the difference between *contractual* delivery date and *actual* delivery date. Almost always a positive number, a plot of representative lead ship delivery delays is provided in figure 10. Typically about a one-year slippage occurs during construction.

Quantitative analysis: Cost

An "end cost" breakdown is summarized in figure 11 which shows typical values for four ship types. "Plans" cost is non-recurring and applies primarily to lead ships. The other cost categories have distributions which vary significantly by ship type. Two things are immediately evident in viewing this breakdown:

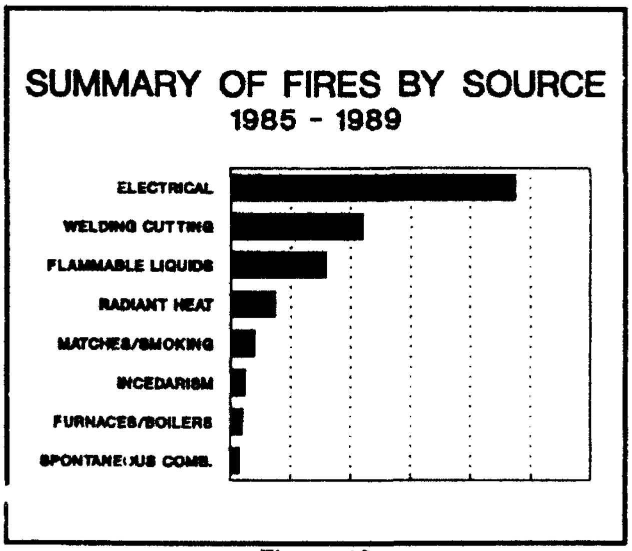


Figure 13

TABLE 2. ROADBLOCKS TO PROCESS IMPROVEMENT
(Representative Sample)

A. GENERAL ROADBLOCKS	B. ROADBLOCKS IMPACTING TIME
•Our customer's difficulty in establishing requirements. •Lack of early effective participation of shipbuilder and vendors. •Lack of continuity across the total ship design process. •Lack of understanding of the entire process. •No definition or measure of effectiveness as it relates to quality. •Lack of systems engineering in the design process. •No process (fragmented process) for combat system integration into ship design. •Overly dispersed talent and insufficient depth of talent in NAVSEA. •No correlation between desired performance by customer and affordability. •Lack of early producibility decisions in the design process.	•Formal source selection process add 9-12 months. •Lack of flexible contracting ability within NAVSEA. •Operational requirements not adequately defined at Milestone I. •No consideration for ship construction from Milestone 0 through Milestone II. •No correlation between systems and ship developments. •Projected contract award date and delivery date not linked. •Shipbuilder has no incentive to reduce time. •Lack of integrated SEA 05/06 /Laboratory approach to ship design. •Full advantage of CAD not being realized. •Too much on-the-job training. •Design teams too dispersed. •Insufficient dedicated personnel. •Too much stop-and-go waiting for approvals or funds.
C. ROADBLOCKS IMPACTING COST	D. ROADBLOCKS IMPACTING QUALITY
•Too many changes after award. •Requirement setting without rigorous capability vs cost. •Lack of cost awareness by designers. •Inefficient shipbuilding practices. • Awards based on low cost. •Late GFI/GFE. •Labor intensive ships. •No design for future flexibility. •Use of out dated specifications, practice and margin. •Concept exploration under funded. •Complexity of the combat system. •Excessive programmatic documentation requirements.	•Environmental impacts not fully considered. •Too much emphasis on cost and schedule vice quality. •Designers not familiar with operation of ship. •Lessons learned are not incorporated. •Operations requirements not properly translated to engineering design goals. •Lack of feedback to designers. •Poorly written specs. •Weapon systems reliability. •Poor workmanship. •Total ship design not NAVSEA #1 priority. •Inadequate Design Tools. •EME/EMI is a black art. •Lack of adequate funding for early design.

- The portion which is directly under the shipbuilder's control, the BCC (Basic Construction/Conversion Cost) is only 25% for a modern surface combatant but up to 90% for a commercial-like 'T' type auxiliary ship.

- Of the total BCC for the three types of surface ships, material, which includes all the major equipment purchases, accounts for about 70%. Overhead is typically 15%. Labor, often viewed as the variable most controllable by the shipbuilder, is a mere 15% of BCC.

Putting these two points together in a hypothetical case which is often heard: if the shipbuilder could reduce labor costs by say half, it would only result in the following total ship end cost savings: combatant - 2%; amphibious ship - 3 %; commercial-like auxiliary - 6%. It is apparent that other cost drivers are at work here.

In addition to obviously being concerned about acquisition cost, it must also be seen in the context of the ship's life cycle cost. Figure 12 has been extracted from [8] to illustrate the relative proportions of life cycle cost components of a typical Navy ship. Note that acquisition cost amounts to only about a quarter of the life-cycle cost and to about sixty percent of personnel cost alone. Acquisition and maintenance cost are comparable. Therefore, a not inconceivable twenty percent reduction in maintenance cost equates to an unthinkable twenty percent reduction in acquisition cost.

Quantitative Analysis: Quality

There is a considerable amount of data available on the quality measures but most of it is too sensitive to be included here. Figure 13 is an example that can be presented and displays the distribution of types of fires aboard Navy ships. Fires fall under the quality category of safety. This

pareto chart shows the relative number of fire-related mishaps over a five year period, clearly indicating that electrical fires predominate over all other types. What will take more analysis is the reason for these fires. At first glance it may appear to be purely an operational issue, perhaps the crew did not follow proper practice for electrical systems operation and maintenance. But this may be only the "surface" cause.

First-hand experience by INSURV inspectors aboard ship sometimes reveals that oversized circuit breakers are substituted for the original ones because of unplanned load growth, such as computers in office spaces. Those of us who work in the Crystal City area are quite familiar with this problem. Subsequent circuit overloading can often lead to electrical fires. Could this have been prevented by designing for more circuit load growth from the beginning? Are design standards inadequate? Is this a classic case of acquisition versus service life cost trade-off? Does this apply only to older ships? These questions call for continued investigation in this area.

In fact, it is almost a matter of definition that quality problems are those ship characteristics which appear as high

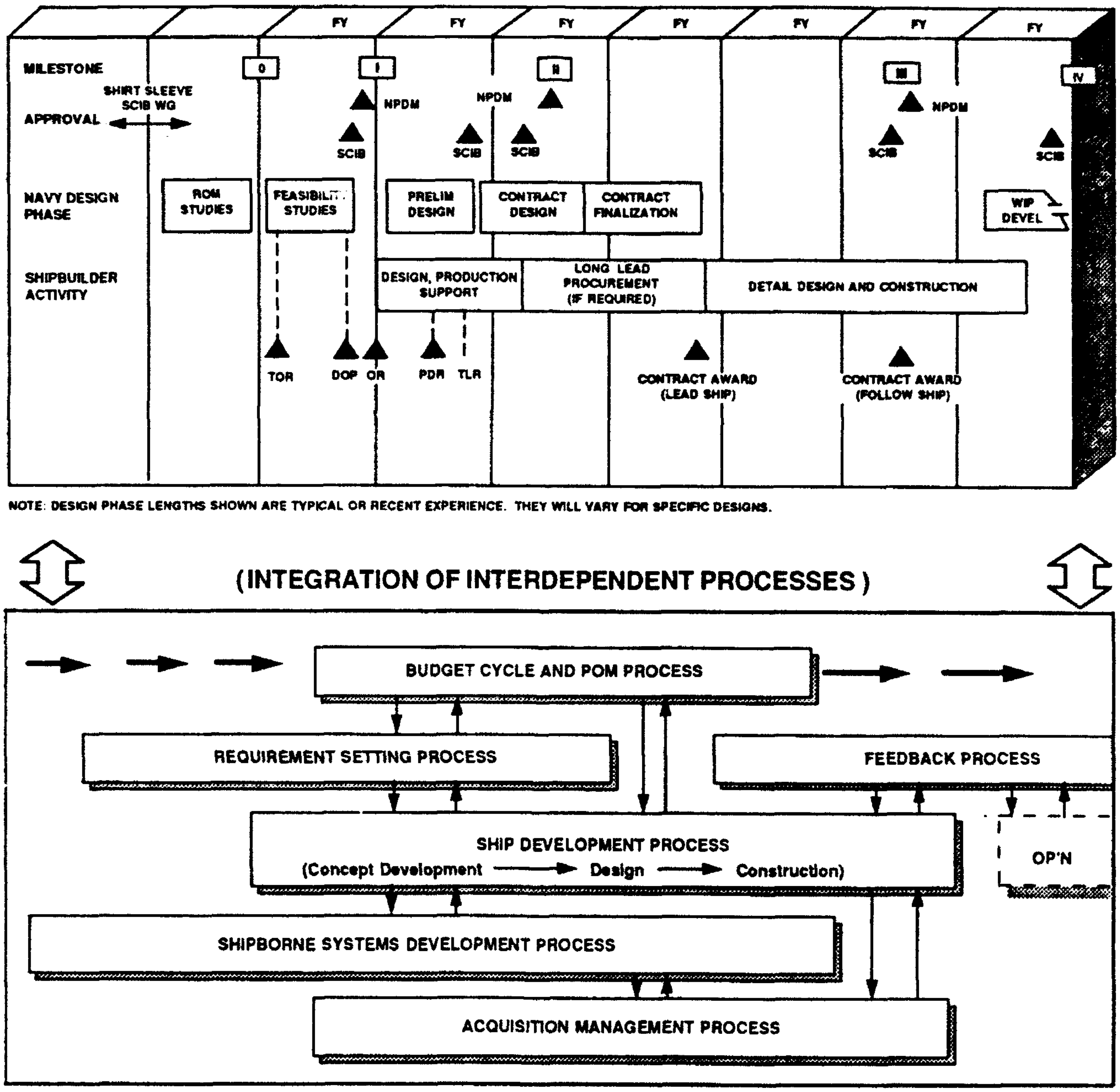


Figure 14. Ship DAC Process as Combination of Interdependent Parallel Processes

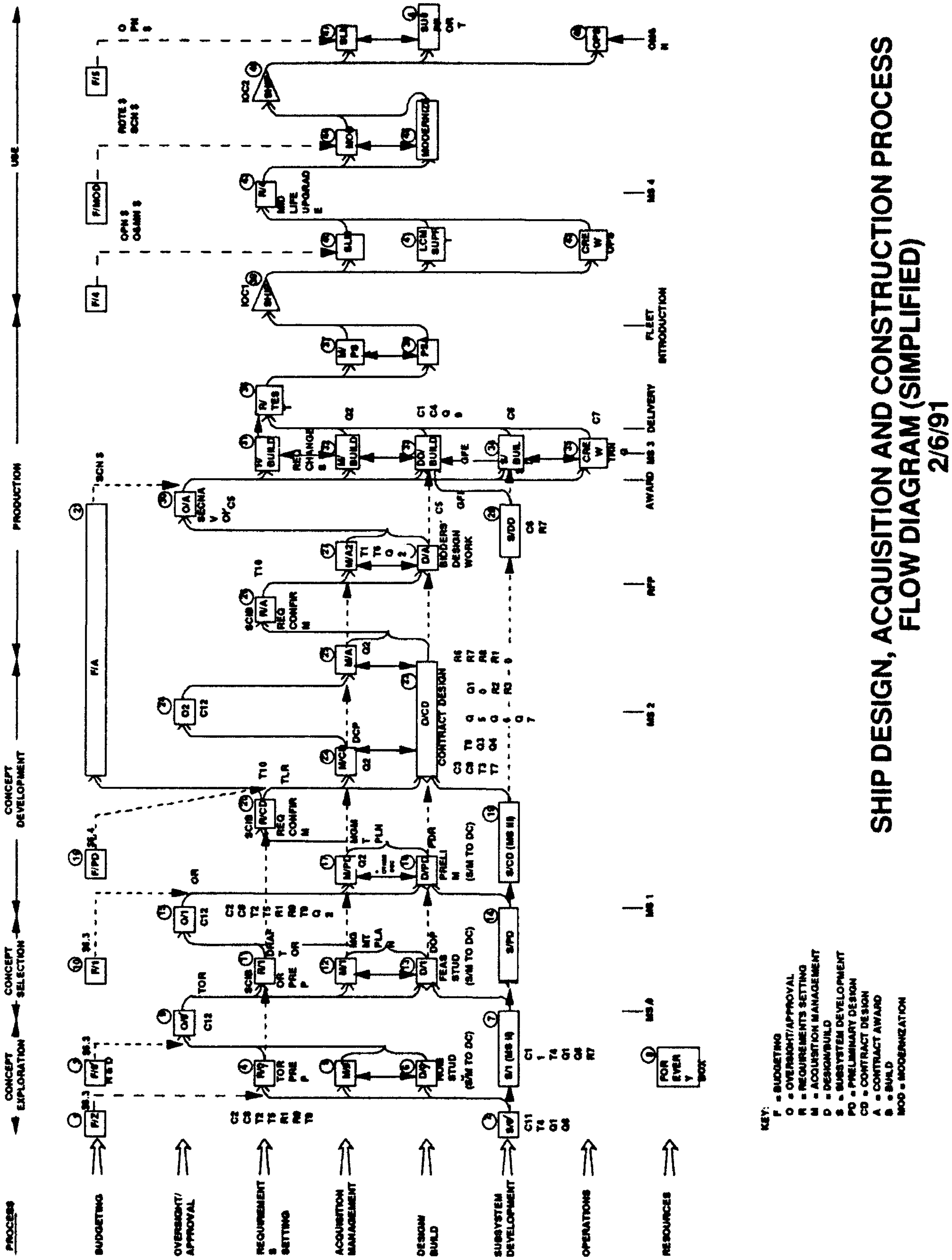

SHIP DESIGN, ACQUISITION AND CONSTRUCTION PROCESS
FLOW DIAGRAM (SIMPLIFIED)
2/6/91

Figure 15

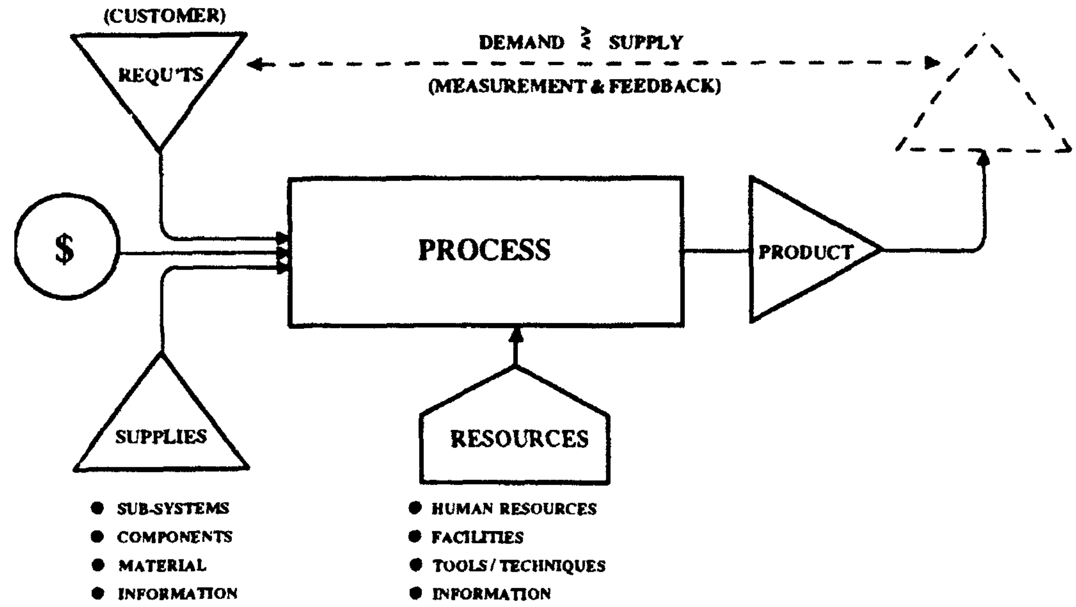


Figure 16. Basic Process Model

cost areas during the service life. For Navy ships, these areas are: personnel, maintenance and modernization, all encompassed in our proposed set of quality measures.

It is apparent that much more analysis should be done to identify the underlying drivers in our DAC process. This project will merely scratch the surface of what needs to become a continuing effort of self-evaluation and improvement.

Roadblocks Everywhere

Insight into the underlying impediments to improvement, sometimes called "roadblocks", "causes", or "drivers" comes from experience coupled with analysis. The two combined may be called wisdom. To the initial analysis work above was added the expertise of our teams, the output from the Richmond Workshop, and the lessons from history derived from Program Offices and past studies. To gain maximum benefit from the time available, we used these resources to compile lists of likely roadblocks to help focus our research. This process is still underway.

What follows is just a sample of likely roadblocks; see table 2. The ideas presented cover all aspects of our process. The reader probably has a list of his/her own. Based on individual experiences, everyone seems to have an opinion of what's wrong with the DAC process.

The advantage of using teams to derive these lists is that through consensus, we can hopefully avoid having to study every possibility and spend our time on the areas where there is the most return.

Solution Possibilities

The quantity of improvement ideas, or solutions, is as vast as the number of perceived roadblocks, by latest count over 160. In examining all the ideas for improvement, we were confronted with two obstacles: the sheer quantity of roadblocks and solutions developed (and included in past, though still relevant studies as well) which needed to be considered; and the overlapping, inconsistent or sometimes contradictory nature of many of these proposals. How were we to present our recommendations in a fashion that would hopefully be more cohesive and compelling? We looked to a deeper understanding of how processes work for the answer.

STEP 4. PROCESS DECOMPOSITION AND ABSTRACTION

DECOMPOSITION

When discussing the attempts to define the process (Step 1), it was noted, that many attempts have been made over the past few decades to fully describe the ship DAC process with results generally at the two extremes. Either the process depiction was so involved and cumbersome as to become difficult to work with; or it was so simple as to become unhelpful. The picture became clearer when we recognized that what is commonly referred to as the Ship Design, Acquisition, and Construction Process is actually the interplay between a number of separate, though highly interdependent processes, see figure 14. These processes include:

- Budget Cycle and POM Process (PPBS)

PROCESS AND SUBPROCESSES

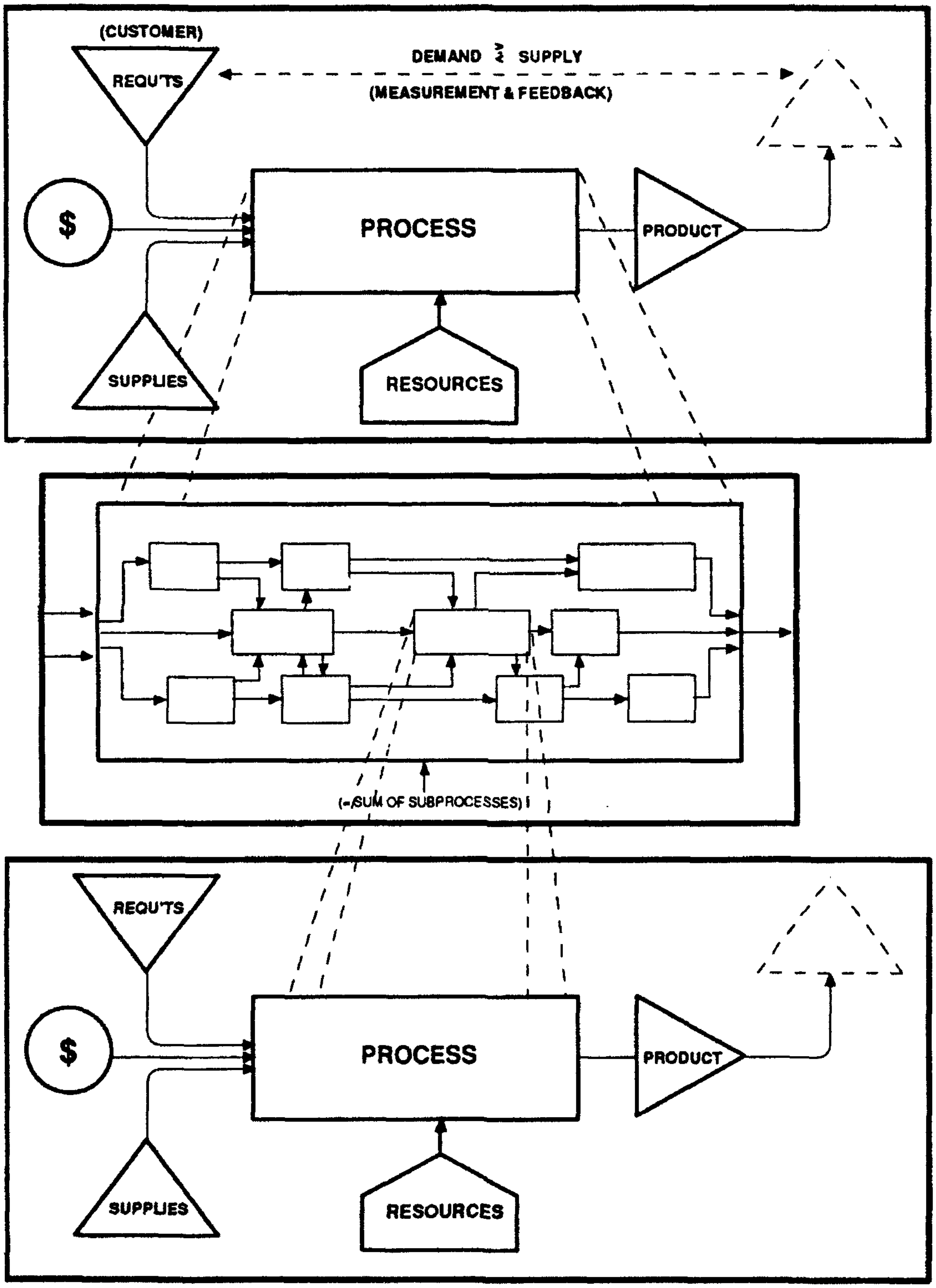


Figure 17. Model for Process Hierarchies

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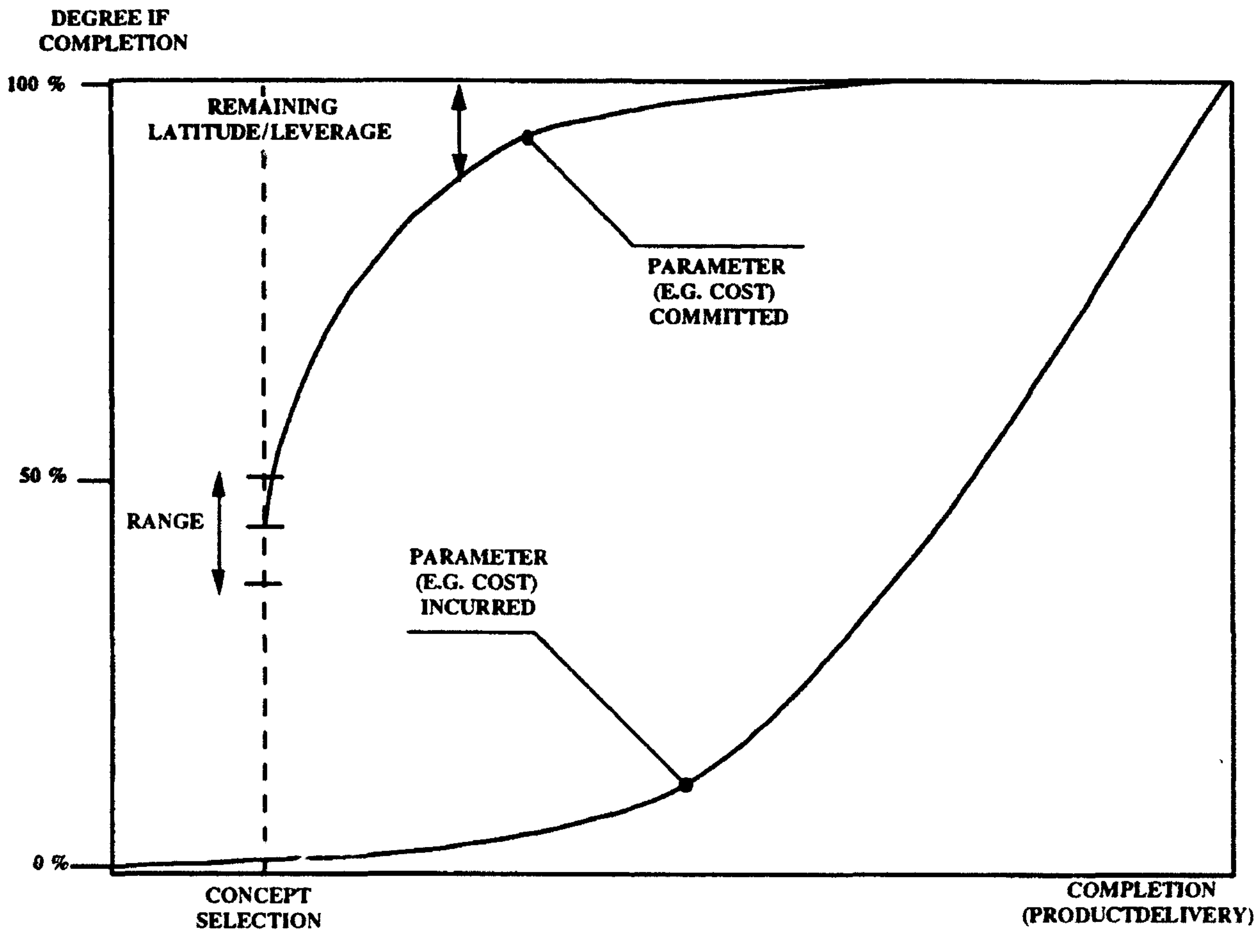

Figure 18. Process Parameters: Incurred vs Committed

- Requirement Setting Process
- Ship Development Pr cess (Design and Construction)
- Acquisition Management Process
- Shipborne Systems Development Process

Also shown is the frequently neglected Feedback Process. However, not shown is the Oversight/Program Approval Process which synchronizes these processes and, therefore, transcends them all. The resulting segmentation of these processes into distinct elements is shown in figure 15.

The need for tools to effectively deal with these elements is apparent. A brief discussion of this tool development follows.

PROCESS ABSTRACTION AND PROCESS MODEL

Process abstraction involves the development of a generic model of a process such that standard features can be identified and generally applicable principles can be derived. Many samples were found in the literature, e.g., [9], [10], [11], with features such as input, process, output, customer, performer, supplier, as well as interactions and feedback between the players. They did not serve our purpose as hoped for. After some iterations, we converged on our own version as shown in figure 16. This model is briefly discussed in the following:

- In a process, inputs are transformed into an output/product. The product may be information/software, hardware or a service.
- The product is intended to meet the demands expressed by the customer in the form of requirements and, hopefully, expectations which form part of the input.
- Other input includes supplies obtained from an (outside) supplier and (in-house) resources (personnel, facilities, tools, techniques, standards and information).

- The "performer" of the process plays the role of both a supplier (when dealing with the customer) and a customer (when dealing with the supplier).

Processes generally consist of many elements, or subprocesses which may be viewed as processes in their own right; see figure 17. Obviously, the top level process and its customer must be afforded the highest priority. There must be a constant awareness of the end-objective, i.e, reducing time and cost and improving the quality of the end product. Nevertheless, every element of the overall process has a customer or user of its product. Similarly every element also is a user of some other elements' products.

Issues relating to processes fall into three basic categories relating to:

(a) the execution of individual processes (intra-process issues)

(b) the interplay between processes (inter-process issues)

(c) resources required for effective process performance.

INTRA-PROCESS ISSUES

When analyzing what occurs inside a given process, two functions are recognized: (1) the actual development of the product, i.e., information (in early stages), and (2) the making of decisions; or hardware (in later stages). Decisions are then reflected in, or imbedded in, the intermediate products, yet have ramifications for the final end product as well as downstream processes.

The extent to which one or the other of these functions is prevalent varies from process to process. In some, the decision making functions may be largely absent, such as in reliability analyses. Others, such as approval processes, produce little in terms of information but consist almost entirely of decision making. Design processes consist of both information development functions and decision making functions.

It is well known that most major decisions, with a predominant impact on the end cost, in particular, are made in early parts of the process — with relatively little cost incurred. Processes near the end of the overall process consist almost entirely of product development; generally product-related decisions have already been made. Costs are incurred, however, at a rapid rate to complete product development.

TABLE 3. PROCESS IMPROVEMENT PRINCIPLES

A. Process Performance Improvements (Intra-Process)	
Process:	Develop the product such that it meets customer requirements and expectations (no defects; no excess).
	Define the product such that it is suitable in format and content for downstream users/customers without reformatting.
	Make effective use of resources.
Decisions:	Make well-informed decisions to support end objectives (time, cost and quality of the end product), yet
	Also consider the needs of downstream processes.
B. Input Improvements (Inter-Process)	
Requirements:	A clear and unambiguous statement of customer requirements and expectations must be developed.
	Uninhibited communication between performer and customer is a prerequisite; techniques such as quality function deployment (QFD) are recommended.
Supplies:	"Treat your supplier the way you wish to be treated by your customer." (Golden rule of Process Improvement)
C. Resource Improvements	
Human Resources:	Personnel must be available on-time as required in adequate numbers at the appropriate skill levels; they must be properly motivated to perform productively.
	Improvements may include additional training, better indoctrination or teaming to achieve aggregate skill levels.
Facilities:	Must be adequate in size and conducive to efficient work performance.
Tools, Techniques and Standards:	Must be suitable for application at hand.
	Must be ready to go; fully tested.
Information: (Corporate Knowledge)	Must be complete, accurate and validated.
	Must be readily available, i.e, accessible and sortable in a format suitable for direct use.

15

This phenomenon of the wide discrepancy between, say, cost incurred and cost committed is illustrated in figure 18. It supplies a strong argument against attempts to reduce the cost of a product by trying to reduce the cost for all process phases. It stands to reason that, on the contrary, it may be very prudent to invest more money (and time) in the early phase to assure that the crucial decisions made at this stage are indeed the best for the entire process and, ultimately, the end product.

We are concerned that this point is often overlooked or not appreciated considering the difficulties to secure adequate funding for early design phases.

INTER-PROCESS ISSUES:

These issues involve the interactions between the performer of a given process with other processes: (a) with upstream processes, i.e., customers and suppliers; and (b) with downstream processes, i.e., users of the product, also to be viewed as customers. Clearly, there must be an early understanding of the needs, requirements and expectations of the customer. An open and active dialogue between the customer/sponsor and the supplier is required to transform what is initially a vague statement of need into the best set of performance/cost/time values available at the time.

Before addressing how to best deal with a supplier, we feel it is very helpful to first reflect on the relationship one would like to have with one's own customer. Then we recommend to simply apply what we propose to term the ***Golden Rule of Process Improvement***: "Treat your supplier the way you would like to be treated by your own customer!"

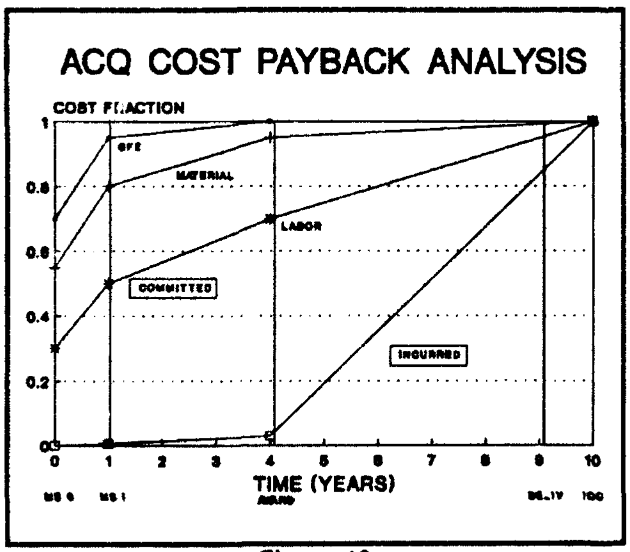

Figure 19

RESOURCE-RELATED ISSUES

The issue of resources has added significance because resources may be inadequate even for the process as currently conducted without the needed or proposed process improvements. Resources represent the infrastructure and include:

(a)human resources, i.e, personnel

(b)facilities, i.e., office space and communication facilities

(c)tools, techniques and standards ranging from computer and synthesis models to standard specifications and design data sheets; and

(d)the combined corporate knowledge in terms of data from previous designs, lessons learned from operational experience fed back, in short: the conglomeration of information which is a prerequisite for a successful process.

Inherent in the provision of resources is the need for upfront investment. The shrinking defense budget, while demanding productivity improvements more than ever, makes it increasingly difficult to obtain these investment funds. A careful analysis of paybacks and return-on-investment will be required.

PROCESS IMPROVEMENT PRINCIPLES

Having thus identified a standard model for any process or subprocess, desirable characteristics for each model element can be derived. Striving for these ideal characteristics leads directly to a set of guidelines, or principles, which universally apply. Table 3 provides an overview of such a set of generic performance improvement principles which, based on the above discussion, should be self-evident.

STEP 5. PROCESS IMPROVEMENT

INTEGRATION

With the insights provided by this examination into how processes work, we now have the tools to complete the project. By matching the process improvement principles with validated roadblocks and solutions for the DAC process, an integrated improvement approach should result. Further, since time, cost and quality are *not* independent variables, the integration technique must center around the subprocess elements themselves.

Specifically, each roadblock identified earlier is categorized by process model element. The resulting groups of roadblocks fall into a limited number of categories of like type. For example, all issues dealing with design personnel fall into those "human resource" categories associated with Feasibility Studies, Preliminary and Contract Design

process elements. They generally deal with only a few common themes: inadequate skills for the job, inadequate numbers of people or overextended personnel.

With roadblocks thus grouped, possible solutions are readily matched. The compilation of all related roadblocks in one place allows the full impact of various solutions to be considered for the whole set of issues. For example, personnel issues can be solved by a selected number of methods: training; hiring; teaming; or specialized tools for missing skills. The training solution would require design engineers to also become expert in: ship production; cost estimating; ship operations; ship maintenance; etc. Clearly, it is unrealistic to expect such broad expertise from individuals even if funds and time were available. Teaming, by bringing together professionals with the diverse expertise listed, is the only realistic solution, and it is implementable in the near term.

By the process of assessing the cost and realism of the various alternatives, the best solution for the whole group of roadblocks can be determined. Solutions derived in this manner should be complete, non-overlapping, and cost effective in addressing the objectives. Roadblock/ solution integration can take place at any level in the process definition. However, care must be taken to avoid suboptimization of improvements by working at too low a level.

MEASURING IMPROVEMENT

Having gone through a rigorous approach to determining means to improve the DAC process, we could simply go forward with implementation. However, the cost of doing so would likely make management want to first look at the potential return. Such "payback" estimating would ideally be done in a deterministic fashion, that is the exact cost (or time or quality) impact of a roadblock's effect on the process is determined beforehand. Eliminating that roadblock would then bring a known quantity of improvement. This approach might work for simple processes, but this information is not readily available for the DAC process. Remember, the impact we are interested is how the improvement will affect the ultimate product, the ship, not just how it affects the specific subprocess where the change is being made.

With sophisticated computer modeling, it might be possible to analyze the impact of any process changes on the time, cost and quality of the ship. Through numerous runs, the "sensitivity" of the ship process to specific improvements could be traded off against their cost or other difficulties of implementation and the best ideas selected. Such a model is being investigated but it is apparent that its development will take considerable time and effort. In the meantime, some other evaluation scheme is needed.

A promising alternative approach might be based on expanded use of a concept introduced earlier per figure 18. It is well known that the early stage decisions in a project "lock in" the downstream costs. This applies equally to time and quality characteristics of the final product. Thus, measuring the influence of early decisions on downstream processes and on end product parameters can be used to estimate the merits of individual improvement proposals. As an example, figure 19 shows a notional breakdown of cost influence factors for Navy ships. When examined in its parts, the GFE, material/equipment, and labor portions of a ship's acquisition cost are "locked in" to varying degrees as the DAC process progresses.

The GFE line indicates that at Milestone 0, where only the type of ship is known, most of the GFE costs are already determined, perhaps 60% to 70%. For example, for a notional destroyer, most of the candidates for major combat system elements are clear, such as major radars, missile launcher types, and sonar system. Between Milestone 0 and 1, a process of refining combat system element *selection* further constrains flexibility in GFE costs, perhaps to 85% of their final value. The number of missiles carried, the number of self defense weapons systems, the extent of aviation capabilities will be determined. Between Milestone 1 (the beginning of Preliminary Design) and award of the shipbuilding contract, the only remaining GFE issues to be resolved relate to the integration of these elements into the ship and to ancillary components, such as: the number of combat system computers and consoles, the exterior communication suite components. By the time the shipbuilder gets the go ahead, there are few unknowns in GFE. Thus, the curves show 100% "lock in" for GFE costs at award.

With similar analysis, the other parts of the ship cost can be estimated as shown. What emerges is a picture of the tremendous importance of the upstream (prior to award) decisions on the downstream costs. Note also in the figure that the "incurred" costs are minuscule until construction starts. It is easy to conclude that the decisions made during shipboard system development, requirements setting and design portions of the DAC process far outweigh the impact of construction approach by the shipbuilder on ship cost. This is not to say that shipbuilding technique is not important, only that the magnitude of payback for certain solutions needs to be looked at in a quantitative fashion before leaping to conclusions on implementation. As a further caution, note that for non-combatant ships, with little or no GFE, the shipbuilder's cost influence factors are greater. This points out the need for the DAC process to have flexibility to adjust to key variables, e.g., ship type.

An additional note on this subject before closing is to restate the interdependence of the time, acquisition cost, life cycle cost and quality factors. We have been told often of the well known trade-off between saving acquisition cost at the expense of life cycle cost. Such trade-offs exist for all the

above variables, with the added footnote that *each* quality characteristic is independent from the others. Each solution will likely increase some values while decreasing others. As a prime case in point, if we accept the premise that decision making during design has much more influence on life cycle cost than construction method, should not more funds be spent during design? The answer is highly constrained by the government accounting procedures which separate funding for design from that of construction, with notably different influences affecting each. This multivariate problem ultimately requires the best judgment of the decision makers to resolve. A lesson learned from this project is that we must do a better job of informing them of their options.

THE NEXT STEPS

Much remains to be done to fully define, even more to make permanent, improvements to the DAC process. Implementation of the first set of solutions requires their prioritization and selection, then planning, implementing, feedback measurement and managing of the changes. As of this writing, it is premature to discuss these steps as they are yet to come.

Put in perspective, what has been started should ideally be seen not as a project, with a beginning and an end, but rather as the start of a continuous process of improvement. Much has been written in the TQM literature on the general principles for achieving this, such as Deming's 14 steps. In support of such longer range goals, this project will provide several elements:

- A framework for understanding the ship design, acquisition and construction process.
- A set of performance measures for ship time, cost and quality. This is sometimes thought of as an "instrument panel" for management.
- New techniques for analyzing large, complex processes such as the DAC process.
- A unique reference library and data base system for accessing information specific to Navy ship design, acquisition and construction.

The ultimate test of this project's contribution, however, will be its effectiveness in making real, measurable improvements to the DAC process. Achieving it will depend on the enthusiasm, skill, and ability of the people involved at all levels to make the necessary changes.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of so many who are involved with this project. First of all, we acknowledge the significant leadership of Admiral Roger Horne in making this project happen. He not only took the initiative to start and get support for this effort but has taken a strong personal interest in its progress, freely offering his time to guide and support us. We also recognize the members of the Executive Steering Group for their continuing enthusiasm and involvement at several levels with the project's activities. On a working basis, over 65 people have given their time as Team Leaders, Team Members, special study staff and support contractors. It is their work which is largely embodied in this paper. The contributions of two people deserve special mention. Ms. Karen Christesen has been a stalwart project assistant since the beginning, keeping us well organized and prepared while providing her own insights into the process improvement effort. Mr. Robert Keane has become our mentor, linking us with top NAVSEA management and injecting much of his own enthusiasm to keep us going. The Team Leaders deserve special mention for their double duty as Leaders and members of Team 1. In addition we would like to thank those who directly supported the project office: Jerry Acks, Kristina Ennis, Chris Whitacre, Bob Jones, Vern Stortz, Dr. Scott Sink, Bob Riggins, Barry Tibbitts, Dave Klinkhamer, Roger Schaffer, and Pete Gale. We sincerely appreciate all the help we have received.

REFERENCES

[1] Sink, S., Coleman G., Ingold E., and Yesso J., "Naval Sea System Command Ship Design Process," Report of Output, Performance Improvement Planning Retreat, 27-29 June 1990.

[2] Garrett, H. Lawrence, "Department of the Navy Total Quality Management Implementation Plan," Memorandum for the Under Secretary of Defense (Acquisition), 4 Nov 1988.

[3] Feigenbaum, Armand V., "Total Quality Control," McGraw-Hill Book Company, New York, 1983.

[4] Crosby, Philip B., "Quality is Free," McGraw-Hill Book Company, New York, 1978.

[5] Office of the Chief of Naval Operations, "Development of Naval Ship Characteristics for Ship Acquisition," OPNAVINST 9010.300B.

[6] Johnson, Robert S., "The Changing Nature of the U.S. Navy Ship Design Process," Naval Engineers Journal, April 1980, pp. 88-113.

[7] Nichols, T. and Rossi, R., "Military Cost Handbook," 10th Edition, Data Search Associates, 1989

[8] Pugh, Philip, "Cost of Seapower," Conway Maritime Press, U.K., 1987

[9] Winner, Robert I., Pennell, James P., Bertrand, Harold E., and Slusarczuk, Marko M.G., "The Role of Concurrent Engineering in Weapons System Acquisition," Institute for Defense Analysis, December 1988.

[10] Sink, Scott D. and Acker, David D., "Managing Quality and Productivity in Aerospace and Defense," VPC, Virginia Polytechnic Institute, Nov. 1989.

[11] SofTech, Inc., "Integrated Computer-Aided Manufacturing (ICAM) Architecture - Function Modeling Manual (IDEF)," prepared for AF Wright Aeronautical Laboratories, Wright-Patterson AFB, OH, June 1981

IS IT SEAMOD TIME ?

Mr. Wade A. Webster
R&D Program Manager
Advanced Naval Surface Ships
R&D Program Management Division
SEA 5112

Special Contribution by
Mr. William Tootle
on Variable Payload Ships
SEA 06R1

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Abstract

In this time of declining budgets and the need for multi-purpose ships it may be time to reconsider the 1972 concept of SEAMOD or SEA Systems MODIFICATION & MODERNIZATION by MODULARITY. This may be better known to you as SHIP SYSTEMS ENGINEERING STANDARDS (SSES) or the Variable Payload Ship - the small, mid-, and large size combatants. The concept is to design and build ships by packaging weapons or HM&E systems in "containers" or modules, on pallets or generally establishing controls for standard interfaces. Some of the different definitions of "modularity" and how they are applied will be discussed. Some history on SEAMOD and SSES/VPS along with the present modularity concepts used by the Royal Danish Navy on the STANFLEX 300, by Blohm + Voss and the U.S. Navy on DDG 51 will be presented. A proposed international Cooperative R&D program for development of interface standards for modular subsystems is being considered. Potential benefits and concerns from modularity in ship design, construction/ producibility, test and evaluation and operational aspects as well as the need for data bus/local area networks to interconnect modules will be presented for your consideration on the "way ahead."

List of Figures

PURPOSE

The purpose of this paper is to ask you, the engineers for the U.S. Navy, to reconsider a concept that would be a major change in the U.S. Navy's ship design/construction philosophy. "Sea Systems Modification and Modernization by Modularity" or SEAMOD is the topic of discussion. It may be better known as the application of Ship Systems Engineering Standards (SSES) to Variable Payload Ships (VPS). This is a TOTAL SHIP DESIGN concept, integrating Hull, Mechanical and Electrical (HM&E) systems and Combat Systems as well as considering the producibility, reliability, maintainability, survivability, etc. and "affordability" requirements. Everyone must "be on board" with this total ship system design philosophy or it will not work. All parties, including the shipbuilders, the equipment suppliers, and anyone else, even Congress, associated with the ship life cycle must want it to succeed! The concept is to design and build ships by packaging weapons, electronics and appropriate HM&E systems in "containers"/modules (or on pallets) and establishing standard interfaces for their integration into the ship. You can't think of it as just a plug in module; you must consider the total "system;" i.e., the module, the ship and the interface between them. But even that is not sufficient. How do you integrate all the modules/containers/pallets into a fighting warship? And what are the logistics problems that will follow? I don't have the answers and this paper will not give them to you. Its purpose is to stimulate your thinking about the concept, - again, and provide a little history on the subject. One major hurdle that must be overcome along this path

is that "bigger" ships don't necessarily cost more - its what you put in them (i.e., weapons, electronics, people, etc.) that drives up the cost. Costs can be driven higher in "smaller" ships by having insufficient room to do efficient outfitting, e.g., too tight an overhead to run the distributive systems properly.

The SEAMOD concept was first discussed by the US Navy in the early 1970's as a proposed solution to the modernization and conversion problem. According to Mr. J.W. Abbott's 1977 paper [1], "SEAMOD is a new concept for designing and constructing Navy surface combatants. It allows the independent (and parallel) design, development and acquisition of weapon systems payloads and platforms and permits interchangeability between the two. It achieves this compatibility through the establishment of comprehensive interface design standards which allow "decoupling" of payload and platform to occur, but which insure their ultimate successful integration into an effective Navy ship." Figure 1 displays this modular payload approach.

This paper will also discuss some of the foreign successes with modular weapons/electronics concepts and a potential NATO Co-operative R&D Program that is being considered. In the 1980's the concept of ship modularity and modular weapon systems was refined and put into actual practice outside the United States by the German shipbuilder Blohm + Voss AG (Figure 2). Blohm + Voss has successfully contracted for 36 frigates/corvettes incorporating MEKO technology (over 1000 modules) with Nigeria, Turkey, Portugal, Argentina, Australia, New Zealand and recently the German Navy. Also, the Royal Danish Navy has instituted a similar ship concept with their STANFLEX 300 multi-mission ship (Figure 3).

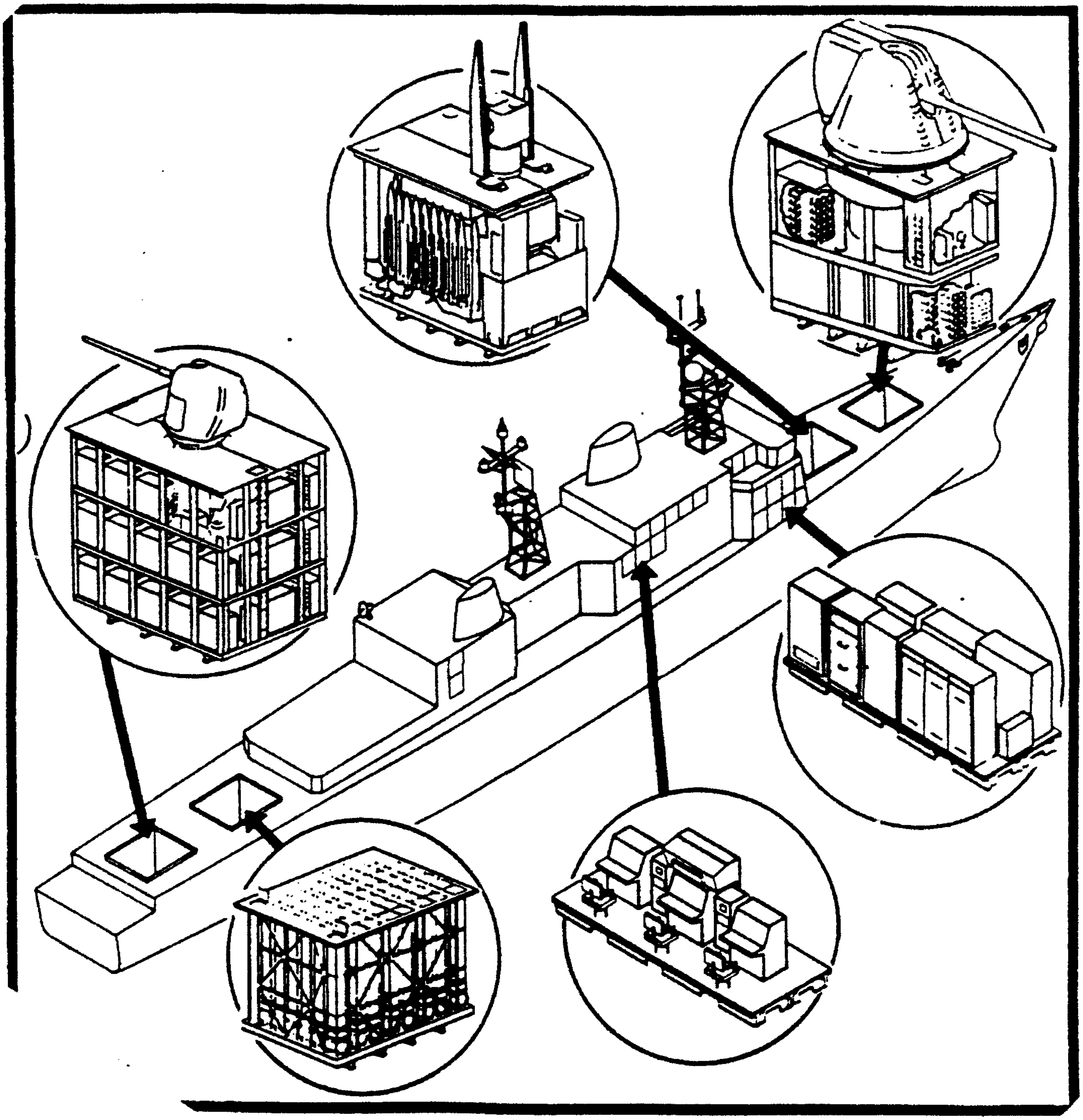
THE PROBLEMS

Surface Combatants with their complex "state-of-the-art" weapons and HM&E systems are taking a longer time to go from concept studies to the ship's Initial Operational Capability (IOC). This can be attributed to many reasons; partially because of the ever increasing complexity of both the combat systems and the HM&E systems, but also because of our highly formalized acquisition process which requires the designers and acquisition people to achieve almost "zero risk" before they proceed with the acquisition. With 40 year ship life expectancies, the weapons and electronics systems are "out of date" before the hull and machinery systems. A recent proposal, when the shipbuilding program was "healthier," was to use "older" ships in roles that required reduced capability, such as protection of shipping, and build newer ships (future flights), incorporating the latest technology, to address the increasing future threat. However the declining budget may cause some reconsideration of this philosophy.

The SEAMOD concept or a similar modular concept (with standard interfaces) should be reconsidered as a potential solution to the Navy's problems of declining budgets and increasing ship costs (i.e.,buy fewer ships, but with easier weapon systems installation/removal for multi-mission capability), and our inability to get the latest technology to sea in a timely manner. The time associated with new system development (both HM&E and Combat Systems) and the design and acquisition of new construction ships is approximately 14 to 16 years. This is too long. In 1975 CDR James Simmons' paper on "Design for Change-" [2] addressed this issue and concluded that "SEAMOD - the uncoupling of the platform and the payload - offers the Navy the potential to put new or modernized ships to sea with weapons systems that are five to seven years newer than would be the case in current practice." (See Figure 4) If we seriously want to reduce the overall ship acquisition time (including the time it takes to get new weapon systems developed, accepted, and to sea) then we must be willing to be open minded and reevaluate the existing process. I believe reduced ship acquisition time, new system implementation (with acceptable risk) and life cycle cost reductions can be accomplished by conducting concurrent ship design and system development via a modular systems approach. By the time a new system is approved for service use and acceptable for installation in a U.S. Navy warship it is no longer "state-of-the-art" technology; computers and electronics equipment may be the best example of this "out of date before in use" problem.

With fewer combatants being built it may be time to consider alternate approaches to provide the needed multi-mission capability as well as an improved modernization capability. Perhaps we can envision ships that are not normally considered to be surface combatants as capable of conducting a combatant role if modular weapon systems could be installed in reserved "space and weight" locations that had pre-wired and pre-piped services similar to "roughed-in" plumbing in a new house. If such module stations existed, adding a gun or missile module, along with its radars, fire control systems and other required systems in predefined weapon zones could be practical and affordable.

Affordability and automation are two "buzz-words" that we continue to hear. But it will take considerable effort on the part of the requirements people (OPNAV) and the designers/developers and builders to reach affordable solutions. The Secretary of Defense is serious about the "affordability" issues as demonstrated by his recent cancellation of the A-12 airplane program. Similar problems may lay ahead for ship programs if we cannot design and build affordable ships (considering not only acquisition cost, but also life cycle costs).

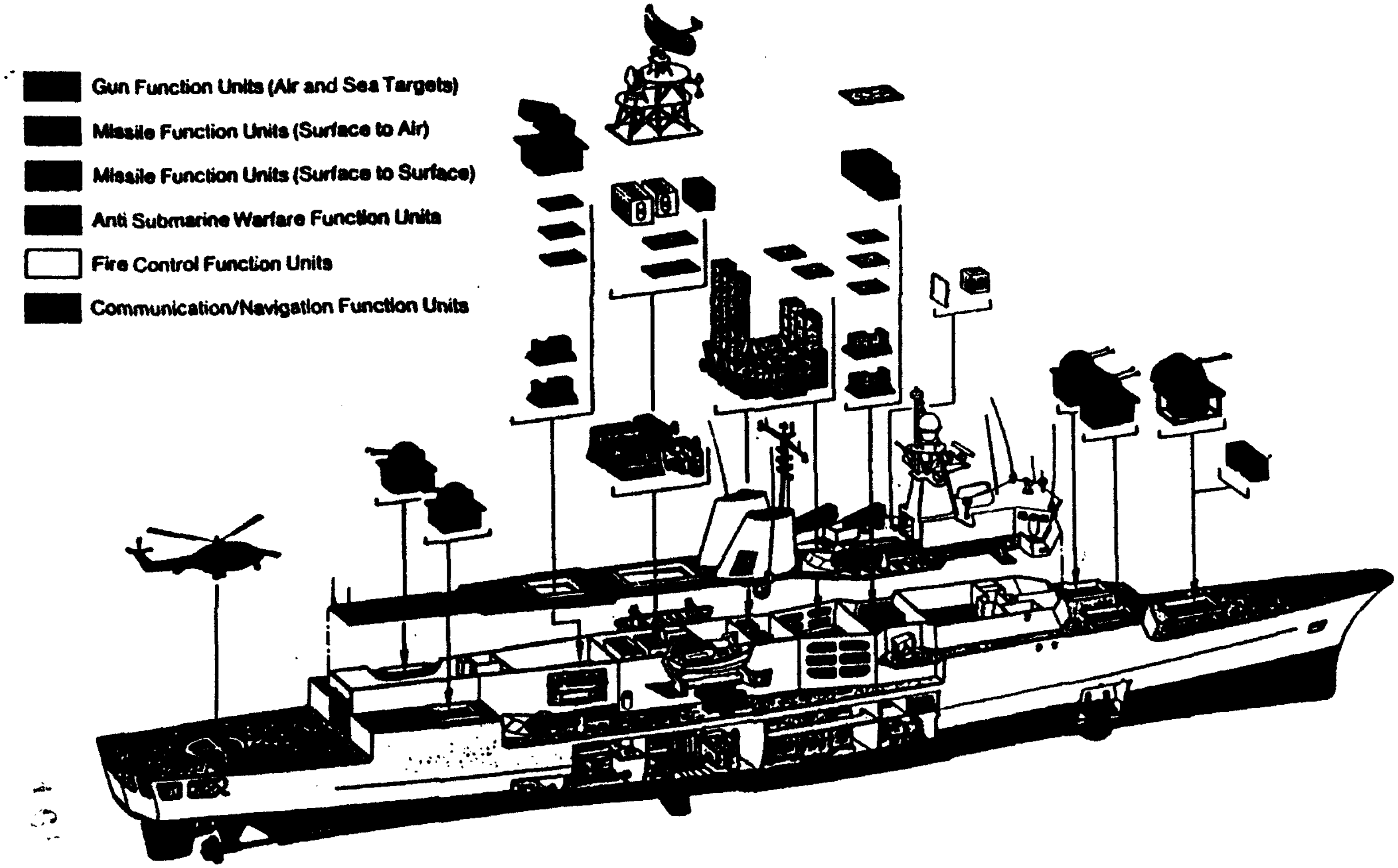


SEAMOD "DECOUPLES" PAYLOAD AND PLATFORM THROUGH THE

DEVELOPMENT OF PREPACKAGED MODULAR WEAPON SYSTEMS, WHICH

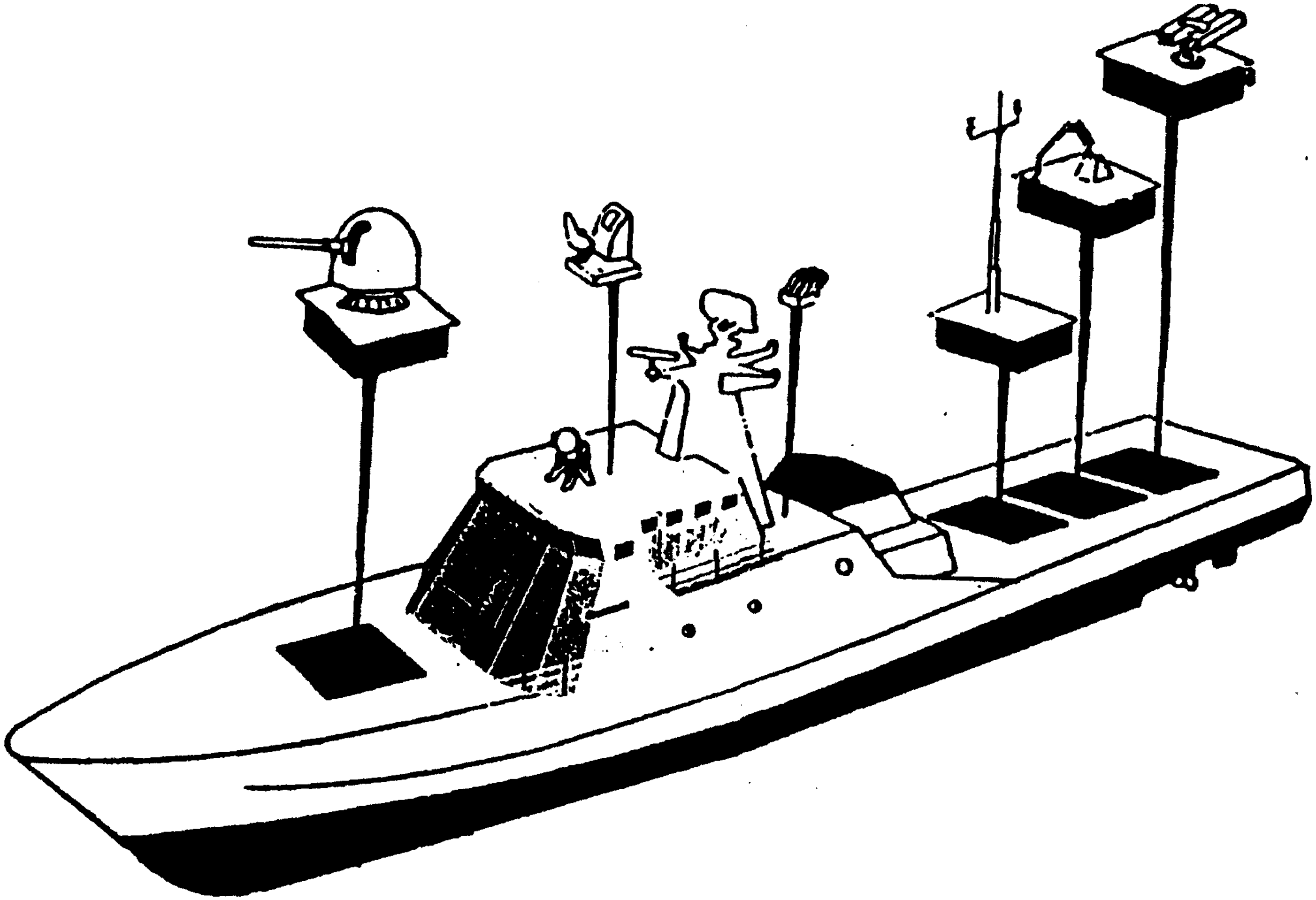
CAN BE RAPIDLY INSTALLED IN SHIPS DESIGNED TO THE SAME INTERFACE

FIGURE 1



THE BLOHM + VOSS MEKO ® /FES ® -SYSTEM

FIGURE 2



DANISH NAVY's STANDARD FLEX 300 DESIGN

FIGURE 3

The three basic questions we must ask when investigating a new system or product are as follows:

(1) Is it needed or wanted by the Navy?
(2) Is it technically feasible?
(3) Is it affordable?

BACKGROUND

DEFINITIONS OF "MODULARITY"

"Modularity" means different things to different people.

"Modular" is defined in Webster's NEW WORLD DICTIONARY as "... units of standardized size, design, etc. that can be arranged or fitted together in a variety of ways."

"Module" is defined as "(1) a standard or unit of measurement (2a) any of a set of units designed to be arranged or joined in a variety of ways, (2b) a detachable section, compartment, or unit with a specific purpose or function, as in a spacecraft, (2c) electronics - a compact assembly functioning as a component of a larger unit."

Before SEAMOD/SSES when I heard the word "module," I thought of "black boxes" or Standard Electronic Modules (SEM)[3]. SEM is an electronic module standardization initiative whose purpose is to reduce the cost of the design, production and logistics support of military electronic systems. SEM can be thought of as a standard circuit card. This type of "standard" is something we have all come to expect in our home electronics and computers. We expect it because we have been told (through advertising) that it is a more efficient way of producing the equipment and cheaper and easier to repair once it has failed to work.

To bring this closer to "home", as my daughter plays NINTENDO next to me, think of the game cartridges with their standard interface that can be simply "plugged-in" or out as one chooses to change the game you're playing. We are also familiar with modular home stereo systems where you can easily add tape decks, compact disk machines, turntables, equalizers, etc. Some people even live in modular homes which are prefabricated to the point of all wiring, cabinets, bathroom fixtures, wall coverings, and even appliances installed at the factory. The homes are usually "trailered" to the site and joined together on the pre-built foundation.

It is interesting that we in the United States understand and accept the "modular" approach and expect it in the consumer goods that we buy,(e.g., the electronics components/games) as well as the cars we drive in or the planes we fly in. Most everything that is built on a production line has some parts or assemblies pre-assembled and tested (e.g., the engine) before they arrive at their integration site on the line.

Some people buy a car with few options installed in hopes that they can add them in the future, when they have more money or when they need the added feature. Luggage racks, trailer hitches, and the most common example is the radio addition/replacement. Most cars today come with a radio installed, but many owners like to replace it with a higher quality unit that can be bought for a cheaper price at a discount store rather than purchased through the car manufacturer/dealer. The standard interfaces of both electrical power and antenna make it easy to interchange the radio. Even the size and location of the controls are usually such that a one-for-one replacement can be made without cutting up the car. Although sometimes customized installation is still required. Since cars are built on a production line, modularity and standard interfaces are mandatory. We can have different engines, transmissions, and many other options installed in the same basic car.

We are well aware of "Modular" shipbuilding techniques used today. The entire ship is broken down into a number of basic construction units, each of which can be finished (pre-outfitted) to as complete a condition as practicable, virtually independent of the others. The DD 963 Class, the LHA and LHD Classes, and many others have employed this construction technique. The dividing up of the hull and the superstructure into structural modules also allows the possibility for construction/outfitting of these modules in different places. The units are then joined together to integrate the entire ship. This is also referred to as the Zone Construction Method which includes the Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM) and the Zone Painting Method (ZPTM). [4] These practices allow shipyards to remain competitive in the ever decreasing shipbuilding market. Time and cost efficiencies were gained through this pre-outfitting of the ship. However, increased up-front planning, engineering and material procurement is required to make it work.

Although we accept these modular or zone construction practices by the shipbuilders, car/airplane manufacturers and the electronics community, and we want modular equipment in our home/car, etc. so that we can easily repair and replace parts, we seem to have difficulty accepting the fact that we could design ships more efficiently and affordably if we accepted and implemented the "standard interface" modular philosophy/process.

In CDR James V. Jolliff's paper, "Modular Ship Design Concepts"[5] he discusses the various definitions of "modular" relative to the shipbuilding industry as follows:

" In ship design and construction the word "modular" has been used to identify anything from large, sometimes pre-outfitted segments of ship hulls to an assembly of several pieces of equipment mounted on a common pallet, to throw-away circuit cards, to a subroutine of a computer software system."

He provides a table of randomly selected definitions of module categories, demonstrates the need for a "universal" classification and provides examples of three major modular systems categories;

1. Construction Modules:
   a. Jumboizing hull sections
   b. Pre-outfitting hull subassemblies
   c. Pre-outfitting deckhouse or assemblies(e.g. helicopter hangar or mast structure.)

2. Large Scale Functional Modules:

   a. Single location Integrated Systems - Today (1991) the Mobile Logistics Support Group in Key West, FL supports the PHM hydrofoils via an interconnected "standard van" complex that can be relocated as needed.
   b. Single location Integrated Subsystems
   c. One or more compartments

3. Small scale Functional Modules:

   a. Component Assemblies (weapons and launchers, gas turbine module)
   b. Components (electronics enclosures and consoles, standard software computer programs)
   c. Parts (throw away printed circuit cards, modular units of shipboard furniture)

Other examples of modular concepts presented included:

ARAPAHO

Provided merchant ships (container ships) with their own indigenous defense; included ASW helicopters, Navy flight crews and support personnel, modular vans containing aviation support and maintenance equipment. The objective was to base an entire aviation support facility in the space that normally would hold containerized freight.

MERCHANT SHIP NAVAL AUXILIARY PROGRAM (MSNAP)

Required development of methods to employ commercial ships to support Navy ships at sea and to deploy forces ashore. Support of deployed forces at sea and ashore with containerships calls for capabilities to remove cargo from containers stowed in ships' holds and to transfer less than container size quantities to customers. The MSNAP program was to develop modular hardware that would provide access to cargo stowed in container holds and transfer it to either combatants or support ships. A Containership Strike-up System (CSUS) [6] or modular merchantman elevator was one concept proposed that would fit into existing containership cells and allow access to the cargo.

CDR Jolliff defined the word "modular" for his paper as: "Pre-packaging of a collection of equipment (systems or components) for the purpose of their assembly and checkout prior to delivery to the ship for installation and for ease of installation and removal of the package (module)."

In Mr. John Drewry's and Mr. Otto Jon's paper [7], they felt that "...the most common error is to define modularity too narrowly - to say that modularity is containerization, for instance. Containerization is, however, a very narrow band within the broad definition of modularity spectrum." Therefore, their broad definition of modularity was the following:

> "Modularity is the physical and/or function grouping of elements of a complex system into building blocks for the purpose of (1) ease of construction, (2) ease of integration, (3) ease of installation, (4) ease of removal, and (5) ease of interchangeability."

Messrs. Drewry and Jon's went on to point out that "...when most people consider modularity, they think only of pre-packaged units that are dropped on board a transport vehicle, used for a time, and then removed (perhaps replaced by another module). Their focus is confined to the module, and if asked to describe modularity, they would talk only about grouping a number of related things, pre-assembling them in a common container such that it is easily movable from here to there, and 'taken off and dropped on' with relative ease. The point is that this view sees only one-third of the whole concept of modularity." Their point was that "...any design solution that employs the concept of modularity must give full consideration, not only to the module, but also to the transporting platform and to the interfaces between the module and the platform."

WHAT WAS SEAMOD/SSES?

According to Mr. J.W. Abbott [1], who was the Director of the SEAMOD Program, "The SEAMOD concept began in 1972 as an overall proposal to consider generic modularity by the Combat System Advisory Group (CSAG) within the Naval Materiel Command (NAVMAT). Until 1975, however, most studies concentrated on where modularity should be applied and surveys of modularity approaches by various navies within the world. In 1975, a study was begun to derive measurable operational, technical, and economic values of SEAMOD by analyzing actual weapons systems hardware, in the

SEAMOD environment, throughout a representative portion of the ship's life cycle. To accomplish this, a fleet unit (the DD 963) was selected as a baseline ship. It represented the Navy's most recent destroyer design and ample data were available from which quantitative comparisons could be made. Actual combat weapon systems were selected for which there were adequate design and cost data. Comparisons were made based on actual engineering solutions in the design of a SEAMOD ship.

The analysis indicated that (as an example) during the ship construction process SEAMOD had the following impact: (a) reduce preassembly by 12%, (b) 22% reduction in preoutfitting, and (c) 20% reduction of on-ship testing.

(NOTE: The SPRUANCE (DD 963) design and production contract at Litton Industries required the ships to be designed for future modernization and conversion, the basic ship program was initiated in the mid-1960's as a DD/DDG development wherein a common hull and power plant design was used with either General Purpose(GP) or Anti-Aircraft Warfare (AAW) combat system configurations. The resulting basic ship was larger than necessary to carry the payload as delivered, and the subsystems were in general oversized to support that payload. The basic ship was designed using a "modularity" concept (and not just hull construction modules); where practical functional entities (e.g., weapons, sonar, etc.) were contained within a set volume. Litton also made extensive use of palletization. See Reference [8]. The DD 993 and CG 47 Classes benefited from this foresight.)

The objective which formed the basis for development of all SEAMOD design criteria was to establish a set of requirements so that 'interchangeability of any or all of the payload elements could take place with a minimum impact on the remaining system(s).' To achieve this objective, a zone modularity concept was utilized for the ship configuration. See Figure 5. Each payload zone is provided with margins of volume and weight and is dedicated to a particular payload function (for example launchers). Furthermore, each payload zone is also provided with support systems (electrical power, cooling water, HVAC, etc.) anticipated to be required after either conversion or modification. Thus, within the zones there remains flexibility of arrangements, allowing changes to be readily accomplished locally without severe impact elsewhere in the ship. Zones had to be selected with consideration given to overall ship arrangement, vulnerability, damaged stability and control, and subsystem demand requirements. Figure 6 shows further breakdown of the zones and modules.

The SEAMOD arrangement requirements were subdivided as follows:

- Module size and location
- Access and interface areas
- Space allocation

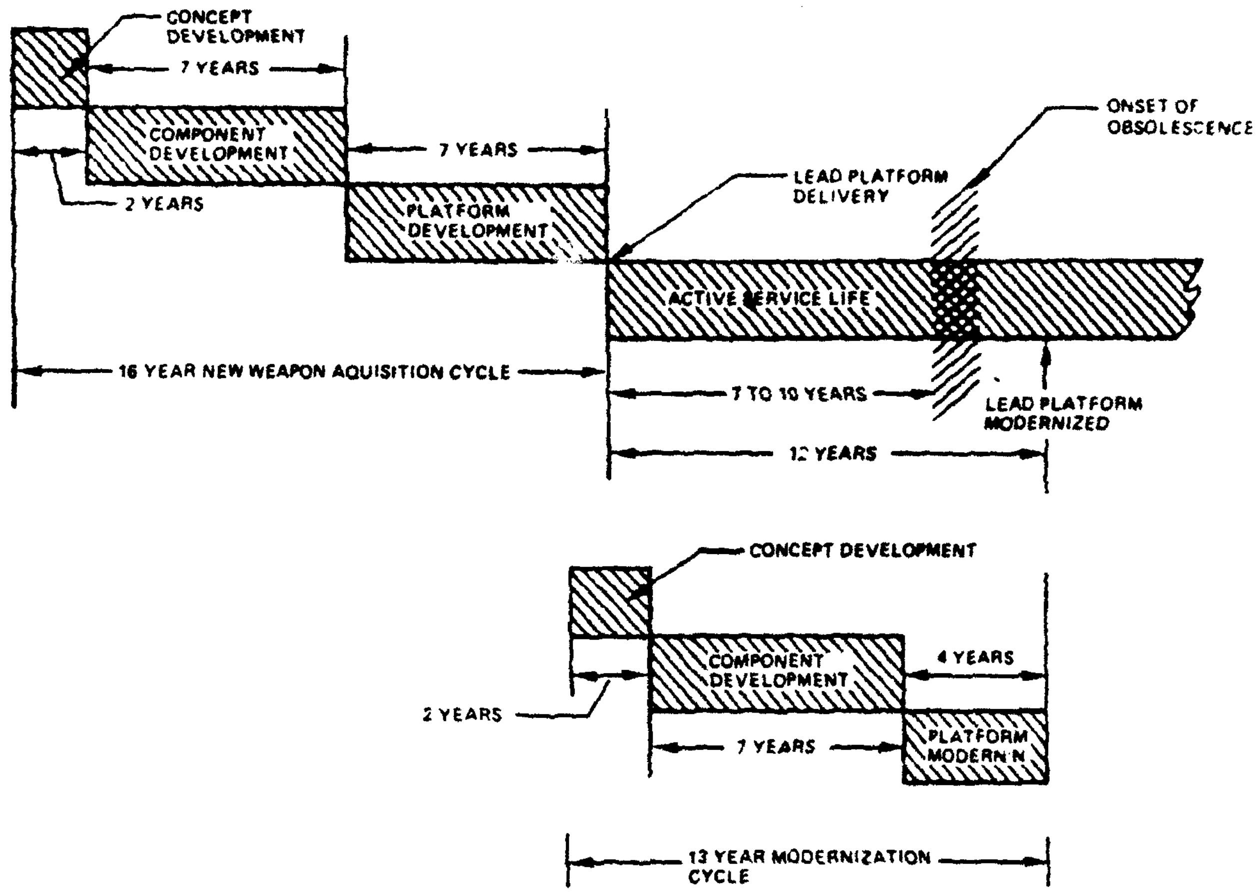
SEAMOD did not claim it would standardize all weapons hardware in the future, but only that the interface between payload and platform would be standardized. As part of the SEAMOD concept, the weapon modules must be capable of being lowered into place within the SEAMOD platform. (The PLATFORM consists of the hull, mechanical, propulsion, and support services systems. A ZONE is defined as a volume on or within the platform which provides access, space, structural support and services for the weapon(s) modules or electronic modules assigned to the zone. The MODULE STATION is the space reserved within a zone to accommodate and support a weapon(s) module. A MODULE is a prepackaged physical unit, usually a functional assembly of weapon(s) system hardware, developed to a specific set of interface standards and specifications.)

Because of the required horizontal clearances between the module boundary and the module station, there is a decision that must be made with regard to damage control, ship protection and access requirements. For example: Which should be made watertight - the module or the hole? or neither? or both? Also should the module be of open frame construction or totally enclosed? The same question can be raised with regard to ballistic protection and where and when it is attached. The following issues were considered when evaluating the impact of SEAMOD on ship design:

- Watertight damage control deck
- Watertight boundary for vital spaces
- Nuclear security requirements
- Ballistic protection for missile magazines

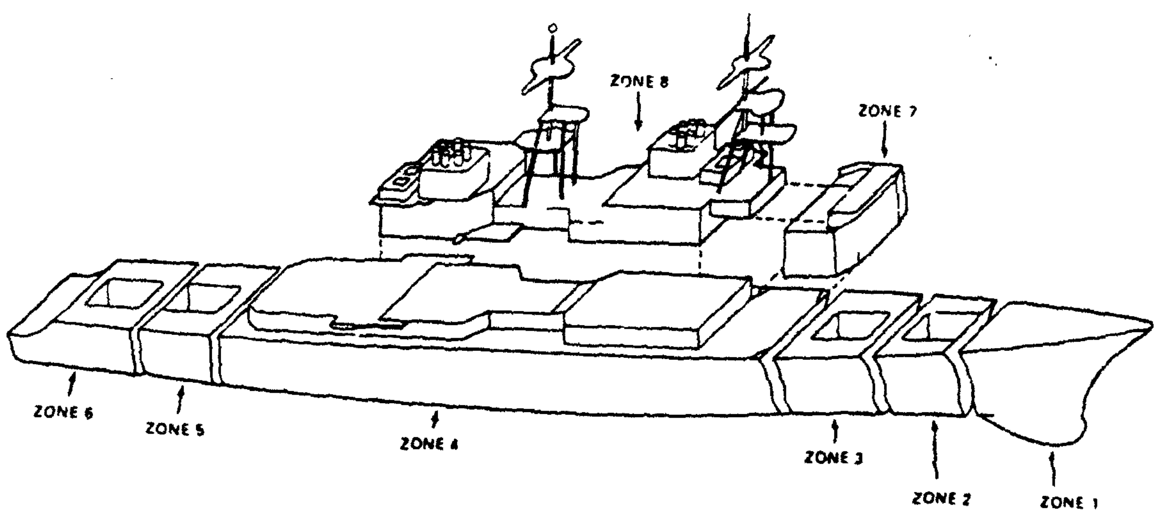
One of the key factors in the development of a platform responsive to the SEAMOD objectives is that the structure of the ship must be designed to facilitate the exchange of payload without major reconfigurration. (SEAMOD/SSES modules were designed for primary support from the bottom, whereas the Blohm + Voss and Danish modules are supported at the upper deck.)

The potential variation in auxiliary support services for various payloads could provide a major obstacle to the implementation of the SEAMOD concept. There are two alternatives with regard to establishing support service requirements:



ACQUISITION/MODERNIZATION CYCLE

FIGURE 4



THE SEAMOD ZONE CONCEPT

FIGURE 5

Zones and Modules

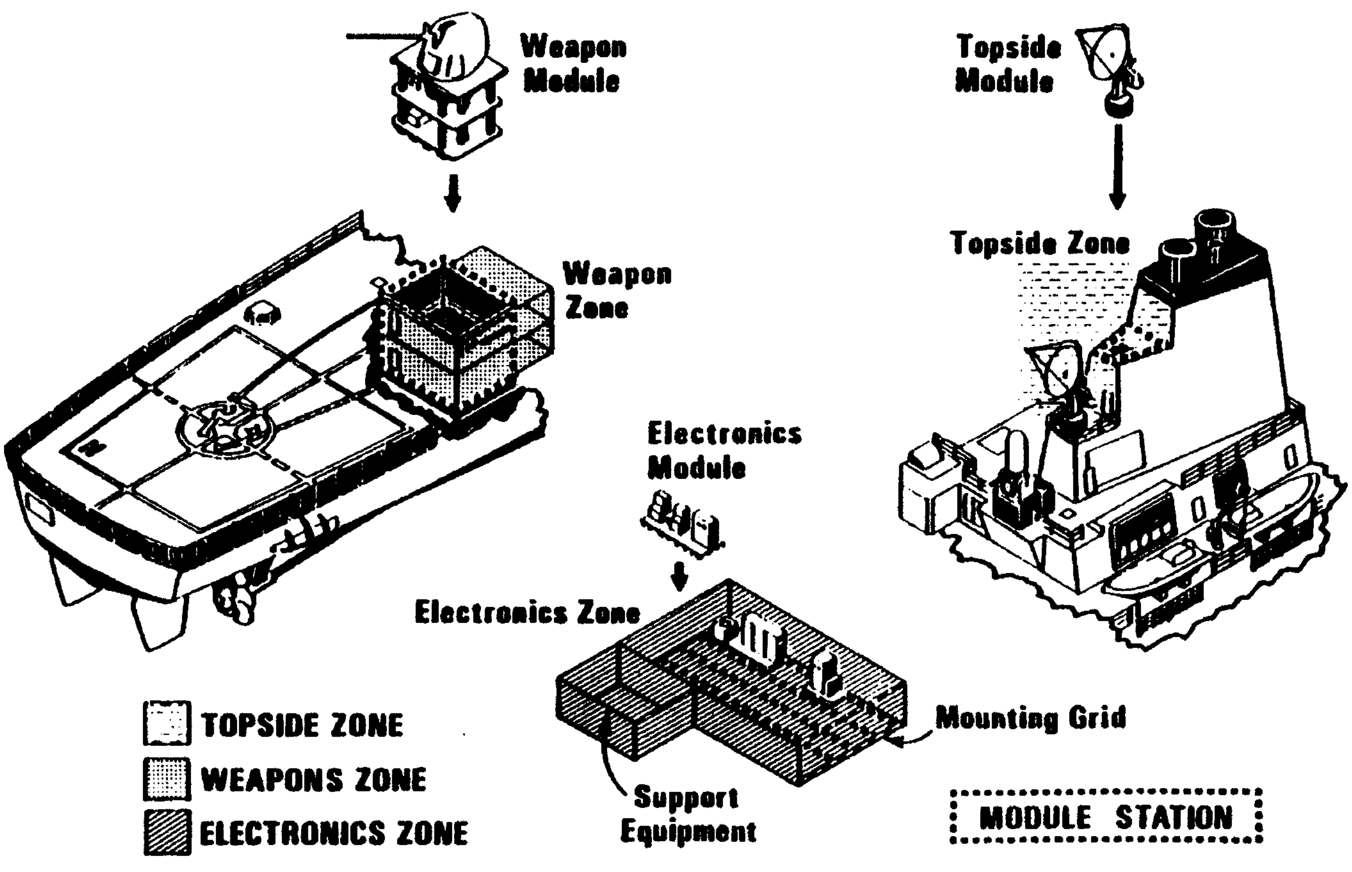


FIGURE 6

- Permit payload manufacturers to establish requirements for their payload as they wish and force ship designers to provide for these requirements.

- Establish a standardized set of reasonable requirement constraints for payloads, based on a careful study of a broad spectrum of payloads, and simplify the overall design.

The first alternative provides great latitude for the payload manufacturer, but significant problems for the ship designer who must configure the platform to accommodate potential fluctuations in requirements over the ship's life cycle. Such fluctuations introduce a conflict between meeting the SEAMOD objectives and meeting design constraints on cost, weight, and space. The second alternative significantly simplifies the ship designer's task, but unless careful consideration is made of its potential impact on payload design it introduces the risk of impairing payload effectiveness.

Payload Design Criteria

The design criteria for the payload must allow the objectives of SEAMOD to be implemented yet be realistic with regard to the state-of-the-art capabilities in technology and producibility. One of the most significant impacts on the payload design will be in the command and control system or Combat Direction System (CDS). The trend had been toward heavy centralization and integration. The result of this trend is that it inhibits any changes to the combat system (payload). It was quickly realized, that if the objectives of SEAMOD were to be reached, a redesign of the CDS would be necessary to allow individual interchange of payload elements without major perturbation to the remaining system. To do this required decentralization of functions and removal of interdependencies that existed. (A key feature of the SEAMOD CDS model was the interconnection of subsystem elements via a data bus network which implied ease of reconfigurration, considerable capacity for functional and physical expansion, and the ability for direct intercommunication between subsystem elements. With these combined features, the potential for fallback and survivability in the event of loss of one or more subsystems is very high.)" [1]

(NOTE - Both Blohm + Voss and The Royal Danish Navy found the interconnecting data bus to be a key factor in the success of their modularity programs. In 1978, CDR Veazey [9] pointed out, "One of the keys to the successful implementation of SEAMOD is a permanent data bus installed in the ship for its lifetime, as is the electrical power distribution system. In the past, during modernization and conversion, the ships have been essentially gutted and rewired point to point between new equipments at a significant cost in dollars, weight and time. Today (1978) progress in several fields, namely microminiaturization of electronics, digital techniques, distributed vice centralized systems, and multiplexed data buses, have made it possible, perhaps even mandatory, to go to a data bus for future systems." CDR Veazey identified three major advantages of the data bus: (1) multiple path data buses will enhance combat system survivability; (2) modular software for the distributed system will reduce life-cycle software costs; and (3) new modular weapon systems can be installed and integrated into the combat system faster and easier. Today (1991) we are still trying to get a full "backbone" data bus system installed in a ship, preferably fiber optic.)

In October 1979, a formal research and development program was set up by the U.S. Navy to develop the Variable Payload Ship (VPS) concept in full detail and to publish the interface standards called the Ship Systems Engineering Standards (SSES).

The goals of the SSES program were similar to that of SEAMOD in that (1) ships were to be designed for a higher level of readiness and availability and (2) to have a lower life cycle cost. In the SSES program these goals were approached by designing the ships to accept alternative combat systems (payload) built to specific interface standards. The design method was to design the combat system elements as modules and design the ship (platform) so that the combat system can be installed after the ship construction was completed and Standardize the Interfaces between the two so they can be (1) designed and tested separately and (2) easily integrated to work together.

The SSE Standards impacted all areas of ship design and support, including (1) basic hull arrangements, (2) support systems sizing, (3) Combat System Architecture, (4) weapon and sensor modules, and (5) future combat system designs. Under the SSES program they developed preliminary standards for AA, A and B size weapon modules. The deck opening size for each of these and a AAA module (developed in conjunction with Blohm and Voss) are as follows:

Module Size	AAA	AA	A	B
Length (m)	4.10	4.70	6.50	9.30
Width (m)	3.50	4.10	5.30	6.50

Figure 7 shows typical "A" size zone applications, with either a gun, VLS, or aircraft support facility installed.

"A"-size Zone Applications

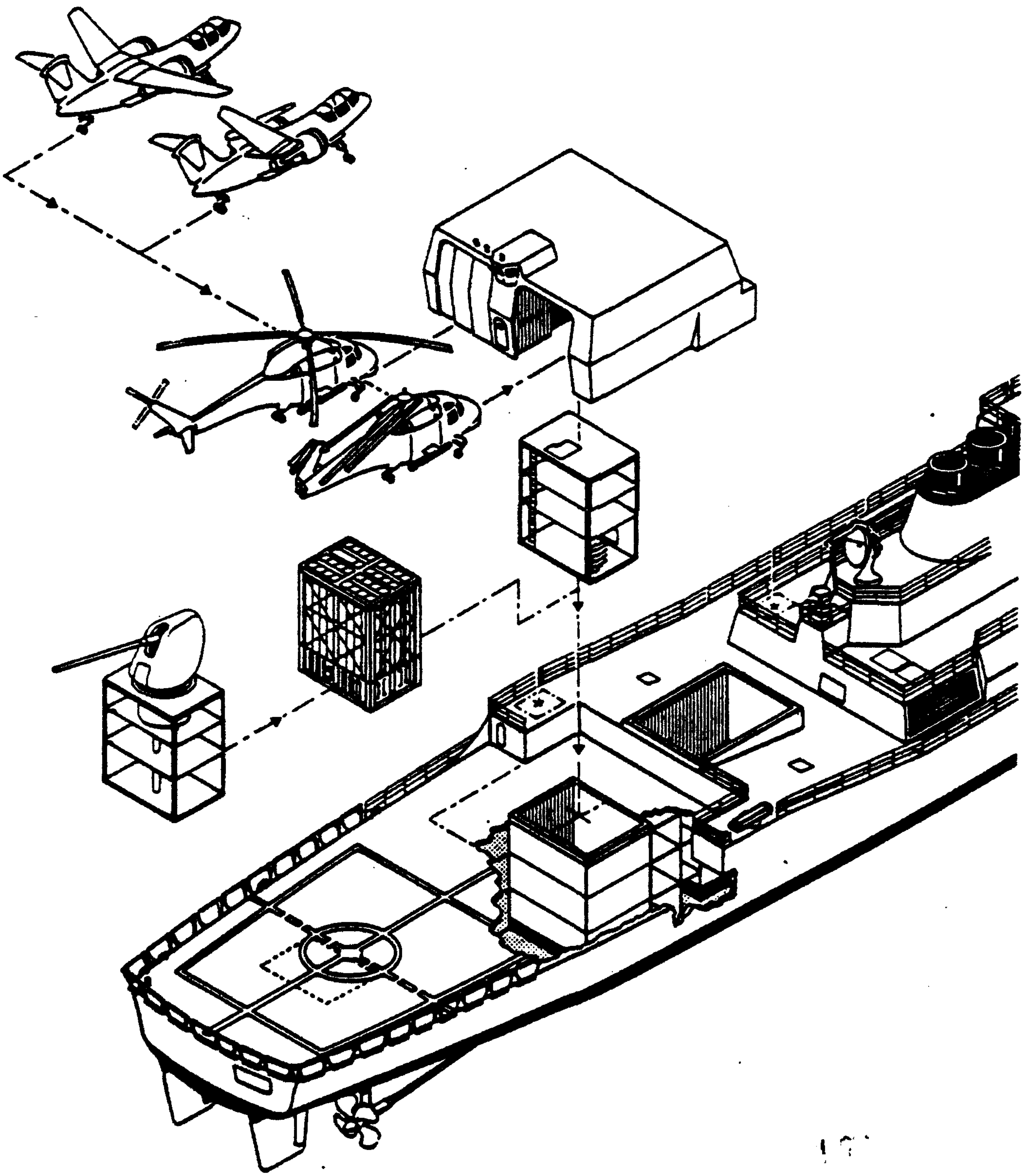


FIGURE 7

RESULTS OF THE SEAMOD/SSES PROGRAMS

The SEAMOD philosophy proposed to have major impacts on

(1) the ship design process
(2) the ship systems design process
(3) the ship construction process
(4) the acquisition process
(5) industry

The encouraging results from the various weapon module studies was that the participating manufacturers felt very positive about adhering to a set of Design Standards - assuming they had sufficient time to design new weapons against them. For the dimensions developed, repackaging of existing weapons was no problem. In order to achieve standardization with the least risk to all concerned, the interface definition would have to be carefully constructed to neither overspecify nor underspecify. Industry participation in the definition effort would be essential to ensure both cooperation and producibility of the end products.

The purpose of the SEAMOD program was to be: (1) the development and validation of the SEAMOD Design Standards (SDS) to be imposed on ship and combat systems designers (later known as the Ship Systems Engineering Standards (SSES)), and (2) the development of a realistic implementation plan to ensure proper introduction of the concept into the Navy acquisition and operating practices. Integrated Logistics Support (ILS) was a critical element in the program. The impact on facilities involved consideration of a Module Installation Facility (MIF).

The proposed MIF is a facility in which the various weapon system modules would be assembled, tested and checked out prior to either being stored in a rotatable pool or installed on the platform. To accomplish this it was proposed that the MIF be organized consistent with Navy regulations and DOD directives. Required technical functions at the MIF included the following:

1. Module assembly, installation, test and checkout.
2. Module changeout, refurbishment and overhaul.
3. Module rotatable pool.
4. Module system level maintenance.
5. Module system level training.
6. Module equipment level maintenance.

The development and incorporation of SEAMOD design standards into a set of Government policy and contractual documents plus establishment of Module Installation Facilities was considered minimum requirements for successful implementation of the SEAMOD concept. [1] (The MIF appears to be similar to the Danish facility in Figure 14.)

According to Mr. Charles Lawson, SEAMOD R&D Program Manager in 1978 [10], the SEAMOD benefits identified by the feasibility efforts were as follows: (1) SEAMOD-configured ships pay a negligible penalty in displacement, volume, speed, endurance, or stability as a result of their modular features; (2) SEAMOD-configured ships can be modernized in approximately one-fourth of the time required for a conventional ship; and (3) life-cycle cost savings for a fleet of 230 SEAMOD-configured cruisers/destroyers/frigates have been estimated to be $188 million per year, based upon a reduction in initial-construction and modernization costs resulting from SEAMOD design concepts.

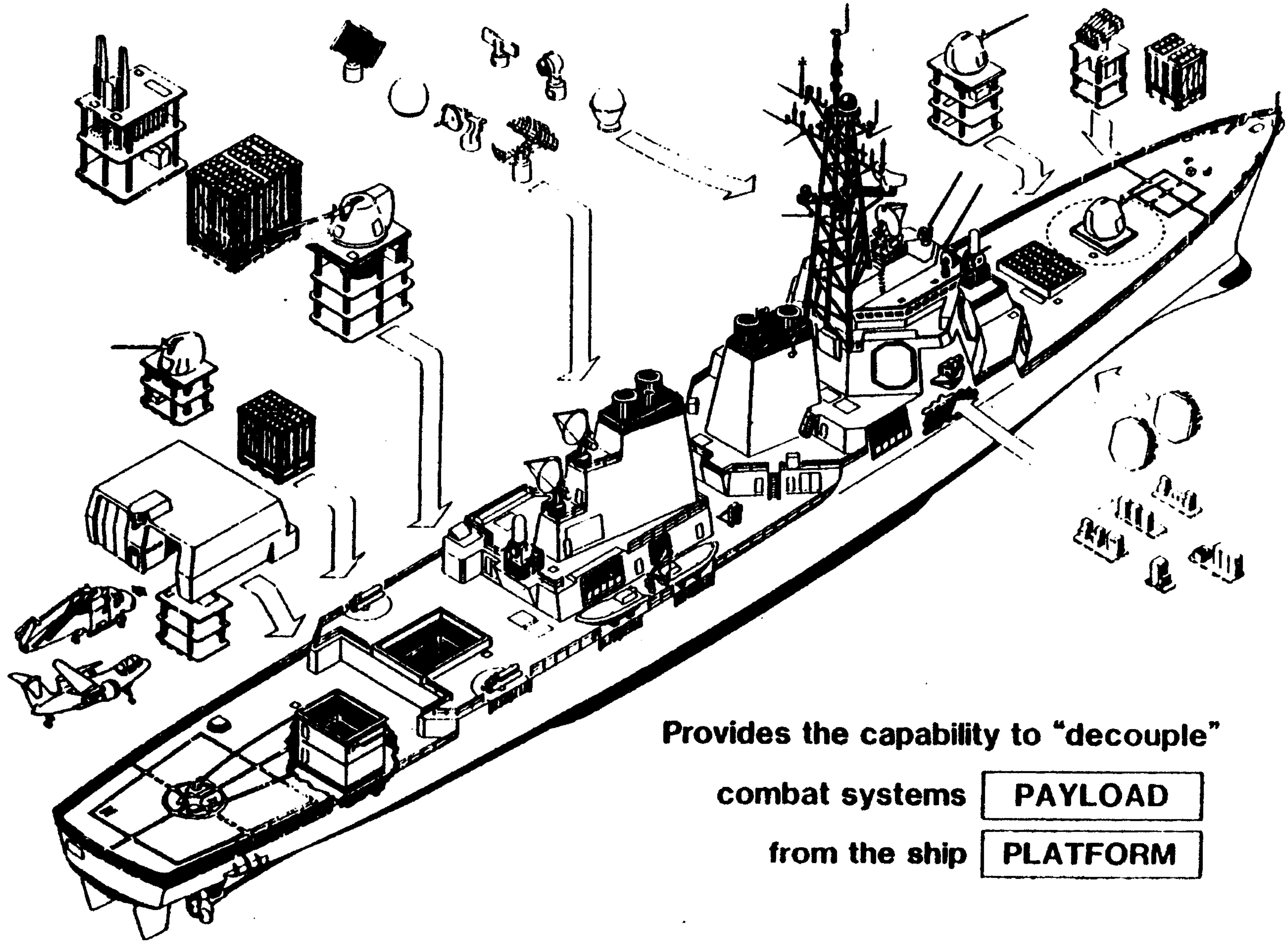
The SSES Program did complete draft standards for A, B, and AA size modules and developed the Variable Payload Ship (VPS) Concepts. As of this date, in the U.S. Navy, only Vertical Launch Systems (VLS) have been installed in weapon modules,(A and B modules on the DDG 51), as envisioned by the SEAMOD and SSES concepts. Designs were prepared for the FFX and NATO Frigate Replacement (NFR 90), but both programs were cancelled. Particular emphasis was placed on the 5"/54 light weight gun in an A module, the VLS modules and electronic equipment palletization for a sonar system.

SEAMOD/SSES DESIGN - The Variable Payload Ships (VPS)

The use of modularity which was developed by the SSES program was called the Variable Payload Ship (VPS) concept,(See Figure 8). The SSE standards would allow the Navy to produce general purpose hulls that could be outfitted with the most current and appropriate combat suite. It was the objective of the SSES program to develop these standards and apply them to destroyers, frigates and cruisers. Implementation of the VPS concept would put an end to construction of surface combatants that were "custom designed" around an initial combat suite selected for the lead ship of a single class.

The technique used within the SSES program to produce a true variable payload ship was the specification of comprehensive standards governing all aspects of the interface between the ship and the combat system. One overall Standard was to be developed encompassing zone, module station, and module requirements for ship platforms, combat system payloads and integration/installation procedures. Comprehensive engineering efforts were also conducted to establish a standard design concept for modularized equipment for VPS electronics

CONCEPT: MODULARITY FOR CHANGE



Provides the capability to "decouple"

combat systems PAYLOAD

from the ship PLATFORM

FIGURE 8

zones. A notional approach to one type of electronics pallet was developed. In selected zone areas, a structural grid (See Figure 9) was investigated as a means of achieving enhanced arrangement flexibility for the large number of individual equipments installed.

The VPS idea was that several distinct sizes of ships could be designed with standard interfaces and, when required, be fitted out for different missions. Historically, combatants were designed for specific missions and were equipped with combat systems that were custom designed. A change in mission or upgrade of the major systems required a major modification to the ship. This process was both costly and time consuming. A process was needed that would allow the concurrent design and development of the ship and combat system; that would reduce the time and cost to upgrade; and would allow fitting out for different mission requirements. Thus the concept of the Variable Payload Ships.

This concept required the development of interface standards for both the ship and the systems to be installed including the combat system. To facilitate the development of the required standard, notional ship designs were initiated. The designs ranged from frigates to cruisers and were designated as follows:

- Small-Size Combatant (3-5 thousand tons displacement)
- Mid-Size Combatant (6-9 thousand tons displacement)
- Large-Size Combatant (10-15 thousand tons displacement)

These designs were expected to satisfy future navy combatant requirements.

One of the first steps in the approach to developing the interface standards was to determine the commonality between the three notional ships. Next, it had to be determined if the ships, HM&E, and combat systems could be partitioned into logical functional areas. The major emphasis was on the combat system. It was determined that to support the combat system requirements of a combatant, the hull could be partitioned into ten zones ranging from an Exterior Sensing Zone to a Special Electronic Systems Zone. (See Figure 10) The intent was to design and outfit the zones to accommodate current and all future requirements. If successful, it would reduce the time and cost for modifications or upgrades. It would also allow the ship to be reconfigured for a different mission, if desired.

In order to fully develop the zone definitions, it was necessary to functionally partition the combat system. An attempt was made to define a "superset" of functions that would be required through the life of the ship and combat system. The result of this exercise provided the maximum volume and ship services that would be required or expected of each specific zone. In addition, the allocated space and ship services for each major function or combat system element (module) could be documented and provided to the acquisition manager responsible for that particular function. If agreed, the zone requirements and function or combat system element requirements would serve as a contract between the naval architect and the combat system engineer.

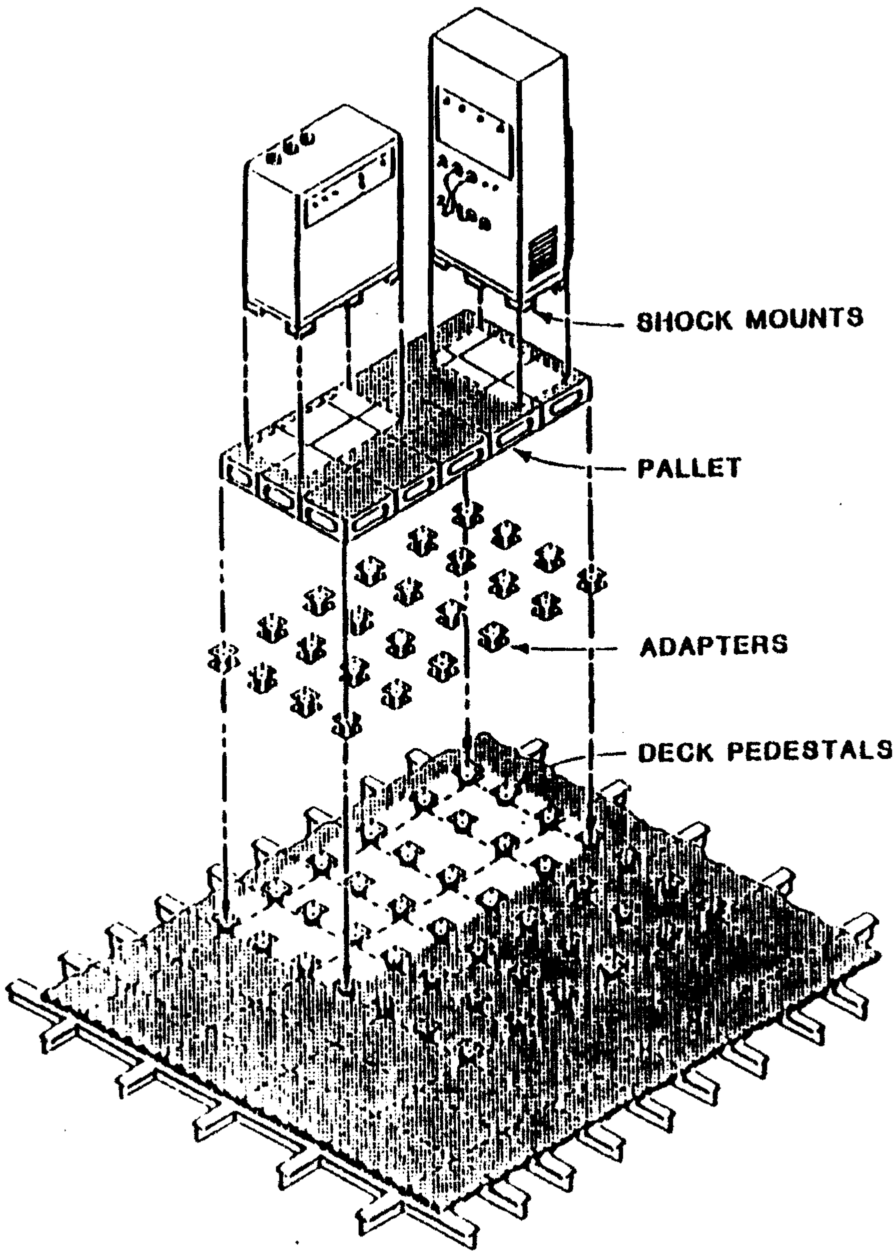
Initial standards were developed with emphasis being on the Weapons Zone and the Weapons Module. An A-size and B-size Weapons Module was included in the DDG-51 design. A complete description of "The Design of Variable Payload Ships" can be found in reference [11] and "The Construction of Variable Payload Ships" in reference [12].

NATO FRIGATE REPLACEMENT (NFR 90) PROPOSAL

In 1982 the U.S. Navy participated in the development of modular warfare systems for NATO purposes when a notional NATO Variable Payload Frigate (NVPF) was prescribed as a candidate for the NFR 90 Program. The NATO nations were attempting to produce a ship incorporating the modular payload design concept which would accept alternative combat system suites made up of systems and equipment designed and built in different NATO countries. NVPF zones, modules and module station requirements were established. In 1985 a feasibility study of a modular baseline platform capable of supporting the eight national combat system variants was completed and included in the October 1985 NFR 90 Feasibility Study Report. In 1986 the NATO Interface Installation Control Program (NIICP) began with the purpose of providing ship systems modularity requirements in terms of weapons and electronics zone requirements and warfare systems modularity requirements. Specific design efforts were in the following areas:

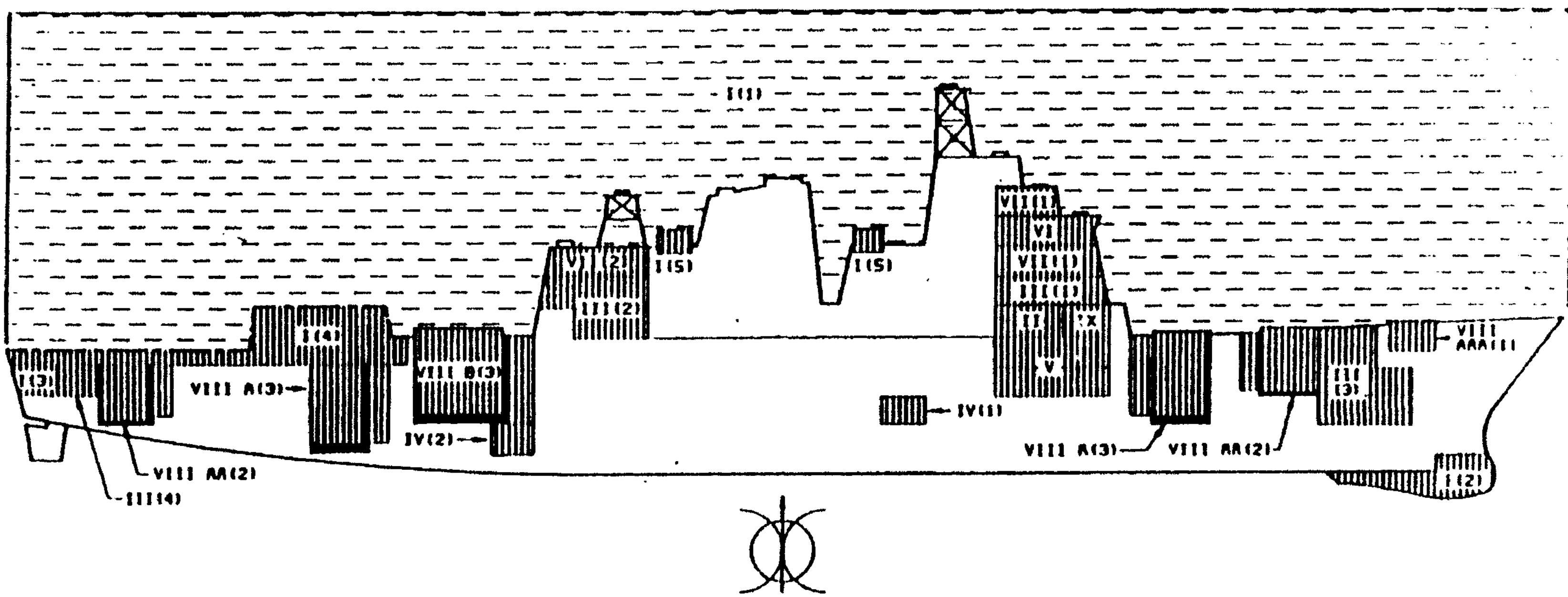
- MK 41 VLS Module
- 5"/54 Calibre Lightweight Gun Module
- Aviation Support Facility
- AN/SQQ-89 Integrated Shipboard ASW System

The objective of the efforts were to provide reductions in ship cost, weight, volume, manning and signatures. Final



STRUCTURAL GRID AND PALLET

FIGURE 9



ZONE I(1)	RF SENSING	ZONE V	COMMAND AND CONTROL
ZONE I(2)	FORWARD ACOUSTIC SENSING	ZONE VI	SHIP CONTROL
ZONE I(3)	AFTER ACOUSTIC SENSING	ZONE VII(1)	FORWARD WEAPONS CONTROL
ZONE I(4)	AVIATION SUPPORT	ZONE VII(2)	AFTER WEAPONS CONTROL
ZONE I(5)	DECK MOUNTED WEAPONS	ZONE VIII AAA(1)	AAA(1)-SIZE WEAPONS
ZONE II	EXTERIOR COMMUNICATIONS	ZONE VIII AA(2)	AA(2)-SIZE WEAPONS
ZONE III(1)	FORWARD RF PROCESSING	ZONE VIII A(3)	A(3)-SIZE WEAPONS
ZONE III(2)	AFTER RF PROCESSING	ZONE VIII B(3)	B(3)-SIZE WEAPONS
ZONE III(3)	FORWARD ACOUSTIC PROCESSING	ZONE IX	SPECIAL PURPOSE ELECTRONICS
ZONE III(4)	AFTER ACOUSTIC PROCESSING	ZONE X	EMBEDDED AVIATION SUPPORT (UNTIL FULL MODULARITY IS ACHIEVED AVIATION SUPPORT ELEMENTS MAY BE MODULAR, EMBEDDED OR A COMBINATION. THIS FIGURE ILLUSTRATES THE MODULAR CASE)
ZONE IV(1)	FORWARD IC AND GYRO		
ZONE IV(2)	AFTER IC AND GYRO		

Representative SSES zone designations and names

FIGURE 10

inputs were provided to the NFR 90 Program Management Office, however, the program was cancelled before final resolution.

The NFR 90 Project provided the forum for the initial definition of NATO modularity requirements. The Ship Systems Engineering Standards (SSES) and Blohm + Voss AG jointly evaluated the key features of their approaches to modularity, thus providing some insight into similarities and differences between their separate programs and were able to identify common ground on which initial weapon modules and zones could be based (i.e., AAA, AA, A, and B size modules). This effort provided the basis on which application effort on the DDG 51 and NFR 90 ship programs and the Vertical Launch System (VLS-MK41) and the Light Weight Gun System (LWG-MK45) could proceed.

NATO modularity was accepted as the fitting of NATO systems hardware into standardized modules and design and construction of a ship platform to accept these standardized modules after substantial completion of ship platform construction.

The modularity concept for the NFR 90 provided two levels of interface control. One at the zone by limiting the maximum capacities of volume, weight, power, cooling, structural support,etc. The second level is at the module station (within the zone) and the module. This control occurs at the configuration definition level by identifying the exact size limits, bolting pattern, module weight, power, cooling, handling and shock characteristics, services interface connection types and location, CG, etc.

FOREIGN IMPLEMENTATION OF MODULARITY

BLOHM AND VOSS - MEKO/FES

Blohm and Voss is a private shipyard located in Hamburg, Germany. In 1969 they decided to implement a new concept of ship construction for surface warships, based on the use of standard modules for the installation of weapon and electronic systems called MEKO/FES (See Figure 2). "MEKO" means a standard ship platform with the possibility of a variable outfit of different propulsion systems and weapon and electronic installations. "FES" means weapons and electronic installations in the form of Functional Units (modules) with standard dimensions and supports and standard interfaces for cooling water, power supplies and data cables. [13] MEKO and FES are trademarks of Blohm and Voss. In June 1977, Blohm And Voss received a U.S. patent (# 4,031,838) for their concept of "Modular Interchangeable Weapons Sub-Assembly System for Warships." The design of the MEKO type ship is similar to that of a conventional warship except that the weapons and electronic systems are installed in the form of Functional Units. Blohm and Voss have found that there is a savings in both time and cost when concurrent construction of the ship platform and the weapon and electronic function units occurs. For them, this means that the weapon and electronic systems can be installed and tested ashore under workshop conditions, independent of the ship's construction process. There is also a clear division of responsibility and coordination between ship, weapon, electronic and machinery manufacturers.

Blohm and Voss primarily use the MEKO system (modularity) to reduce the time and cost of ship construction. According to Blohm and Voss the MEKO/FES system permits them to award a contract with a supplier for a particular equipment, ship the supplier a "container" for equipment installation and test, have the container sealed after factory testing and then shipped to the yard when ready for installation in the ship or needed for other dockside testing. When both Blohm and Voss and the equipment supplier are ready the seal is broken, the container inspected and dockside testing conducted as required. Installation in the ship is then carried out according to the preplanned schedule. A key feature of the MEKO/FES system is that the module openings provide access to the rest of the ship while the modules are pierside. After all systems are installed which require this access the module is lifted into place. Also, if for some reason a module is delayed at a supplier and it is not critical for ship operation, builders trials can be conducted without the module, but with a module station cover in its place.

Blohm and Voss and the U.S. Navy have cooperated on standards for surface warship weapon modules since 1982. As previously mentioned, there is general agreement on the AAA, AA, A and B sizes. Compatibility between SSES and MEKO/FES was based on common:

- deck opening sizes
- bolt hole patterns
- bolt hole spacings
- bolt hole diameters
- base supports for VLS

The MEKO/FES concept allowed flexibility by using a nesting concept which permits a smaller module to be installed in the next larger module foundation by turning it through 90 degrees (e.g., AAA fits into an AA). In addition to the four "standard" sizes, Blohm and Voss also has a fifth size weapon module, the (A), in order to com-

plete its nesting concept. The (A) fits between the AA and the A. Blohm and Voss also build containers for the electronic systems. Systems such as radars, sonars, EW and radio communication installations can be accommodated in Electronic Functional Units (EFU), conforming in height and breadth to standard ISO container dimensions, and varying in length between 3.0 and 4.5 meters to take account of the many varied systems. Because of the use of the standard ISO containers, the EFUs can be transported by truck. Figure 11 is a representation of the EFU. Functional units in the form of pallets are also used for electronics equipment and mounting of operator and tactical consoles. See Figure 12.

The MEKO/FES concept is now in its third generation. The MEKO 360 and MEKO 140 corvettes were the first generation. The MEKO 200T frigates (for the Turkish Navy) are the second generation and the MEKO Mod 3 is the third generation. MEKO Mod 3 has 4 primary developments, according to Blohm and Voss: (1) standard foundations for weapon and electronics modules compatible with SSES, (2) a data bus system (the Multi-Interface Computer Equipment (MICE) in conjunction with the digital Data Information Link Network (DAIL)) (3) further reduction in the ship's above water signature, and (4) increased survivability, passive self-protection against splinters, and Integrated Missile Defence System (IMDS).

From Blohm and Voss's recent successes in MEKO/FES ship sales it is obvious the weapon module/container system of design and shipbuilding works for them and is profitable. For additional information see reference [13] and/or contact the local Blohm + Voss AG representative (Falls Church, VA.).

ROYAL DANISH NAVY'S - STANDARD FLEX 300:

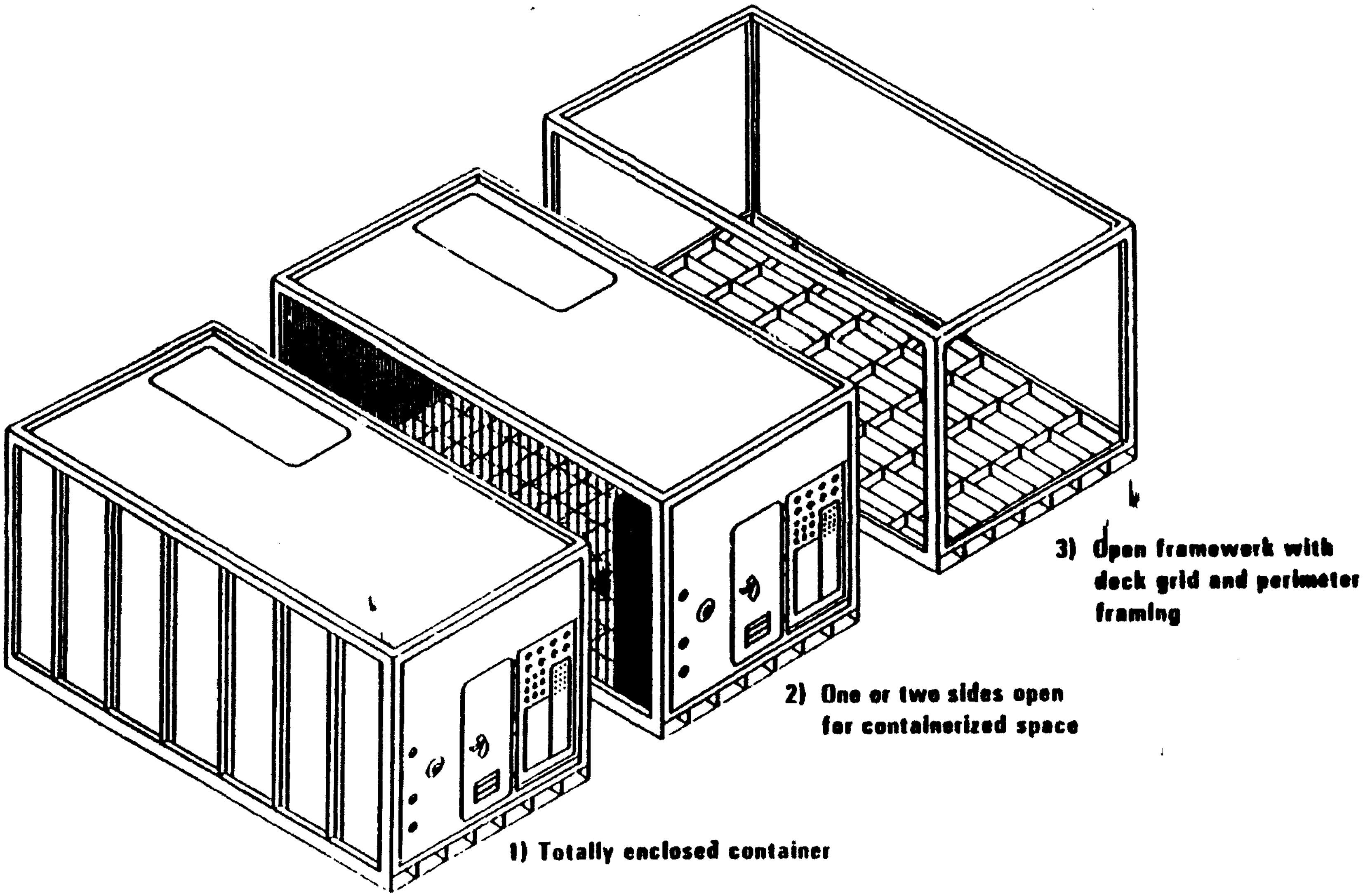
During the early 1980's, The Royal Danish Navy were planning for the replacement of up to 32 ships in the 1990's which performed various roles (fast attack craft, patrol craft, and mine countermeasure craft); for a smaller navy like the Danish this was a large number. They selected a base platform, the Standard Flex 300 (See Figure 3), with rapidly exchangeable modular systems (containerized armaments and equipment) as a means to match the platform to the various roles. A total of sixteen FLEX 300s are planned. Figure 13 is a representation of the four different configurations planned for the STANFLEX 300; i.e., surveillance, minelayer, missile boat, and mine countermeasure. The Royal Danish Navy's feasibility studies [14] indicated that in a hull length of 54m, beam of 9m and approximately 300 tons displacement they could install four "wells" (module station), each dimensioned to take any of the planned weapon/equipment containers. All "wells" were on the centerline with one forward and three aft of the superstructure. The basic idea is to mount weapons and non-permanent equipment in "standardized containers" (to Danish standards) to allow rapid change for different roles. The size of all the "containers" (open sided or closed) is 3.0m long, by 3.5m wide by 2.5m high. The principal systems that are to be containerized are the forward gun, deck crane, inflatable boats, various missile and rocket launchers, torpedo, radio-link antenna, and minelaying and hunting gear. Figure 14 is a drawing illustrating the concept. The concept also offered flexibility as far as budgeting was concerned. The build-up of the various modules for each role can be paced as funds allow.

Also identified by the Danish as a key feature in making modularity a practical solution is the implementation of a data bus. According to CAPT S.T. Petersen (now RADM) [15], " So far, until the advent of the data highway or data bus, which is being fitted into the SF 300, the integration of equipments which are radically different in nature was only possible through human interface and complex hardwired systems. This fact indicates that operational and logistic flexibility in hardwired ships is not present (or only present to a limited extent). The SF 300 data highway system, built into every single standard hull, the standard display console and the standard container - the latter two with standard mounting and supply interfaces - allows for easy and fast connection of modular weapon systems in preplanned positions." Figure 15 is an artists layout of the STANFLEX 300 data bus. [14][15]

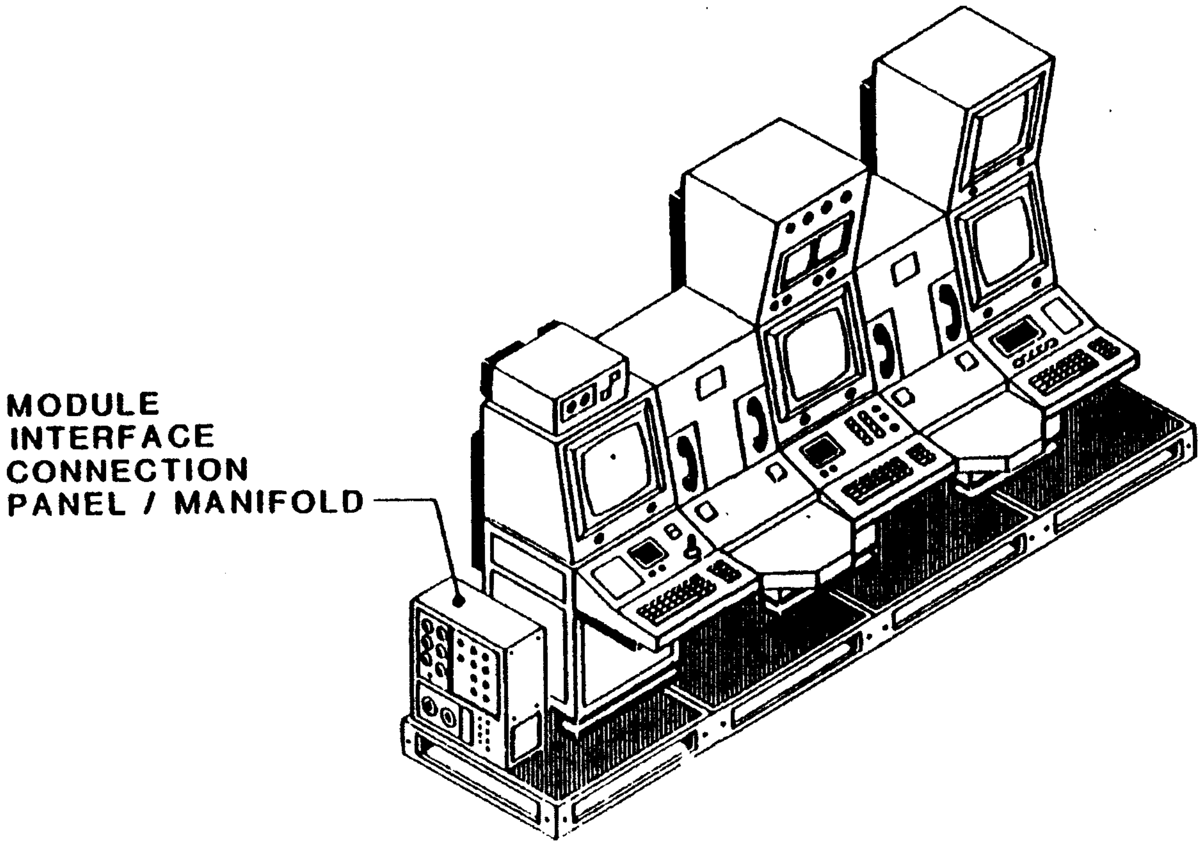
Another interesting feature is that the STANFLEX 300 hull and superstructure are built by use of the glass reinforced plastic (GRP) sandwich method. The main reasons for this method were considerations on weight, maintenance, and the non-magnetic property of the material. The first hull was built by the Swedish yard, Karlskronavaret. Following construction of the first hull and fitting of the superstructure in Sweden, the unit was shipped to Aalborg Vaerft (member of Danyard Group) in Denmark for completion. All remaining hulls are to be built at Aalborg. The STANFLEX 300 also incorporates rudder roll stabilization, designed and manufactured by Brown Brothers (part of Vickers Marine). [16]

PROPOSED INTERNATIONAL COOPERATIVE R&D PROGRAM

A Candidate Nomination Proposal for a Cooperative R&D program is being prepared for the development of interface standards for modular subsystems. In 1988 a program entitled "Interface Control for Modular Installations" was proposed and a Statement of Intent was signed with the Danish to further investigate standard interface

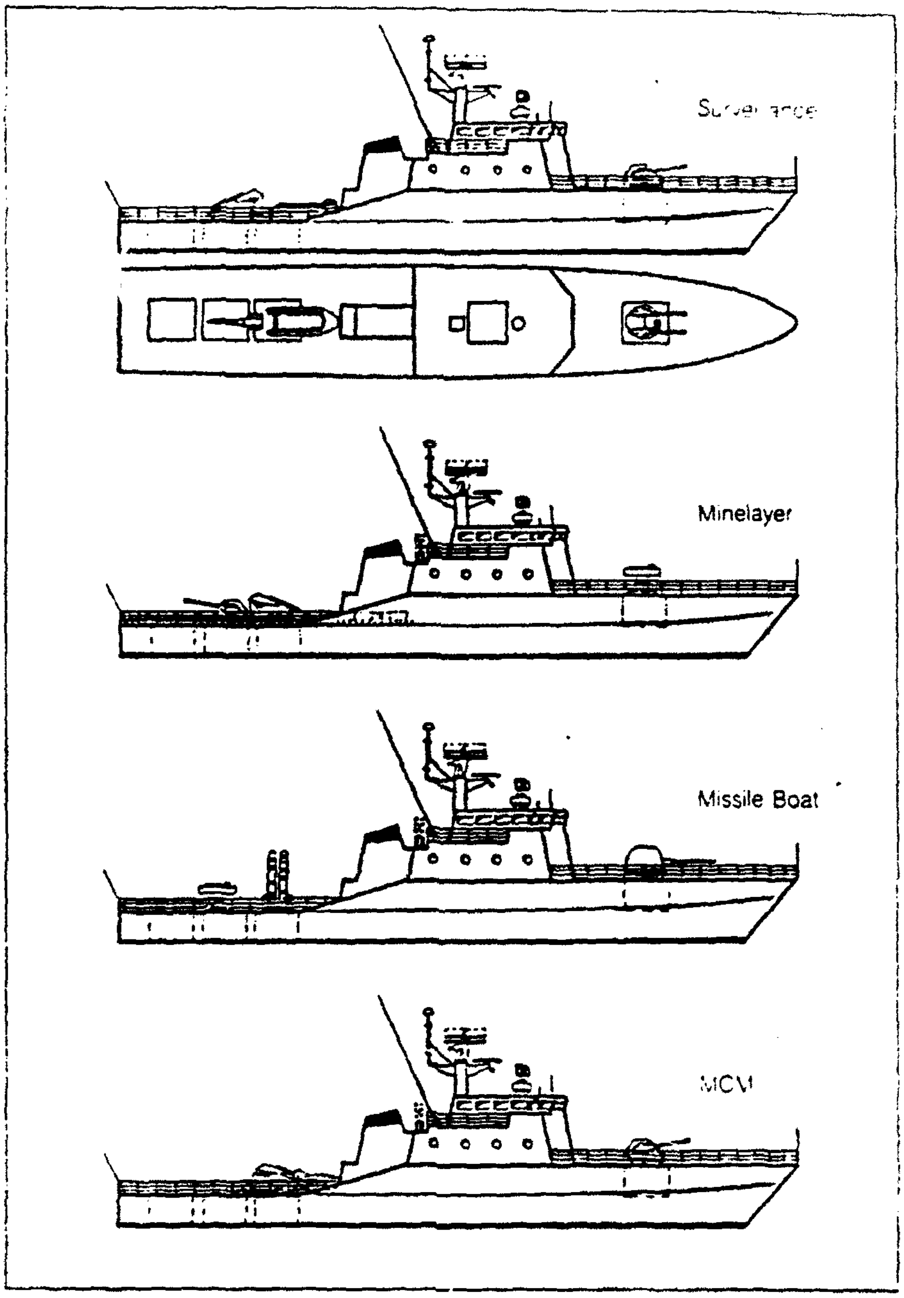


E-module Configurations
FIGURE 11



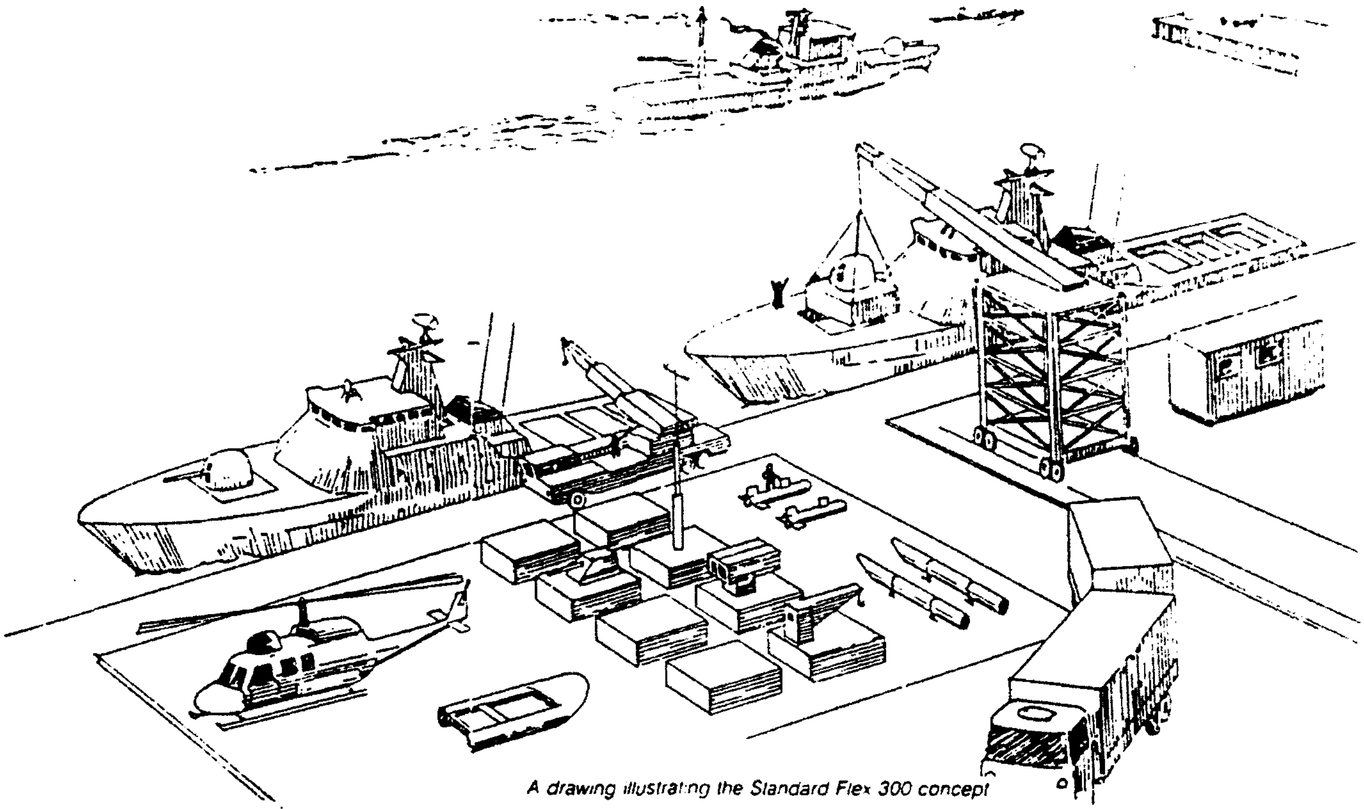
PALLET MOUNTING

FIGURE 12



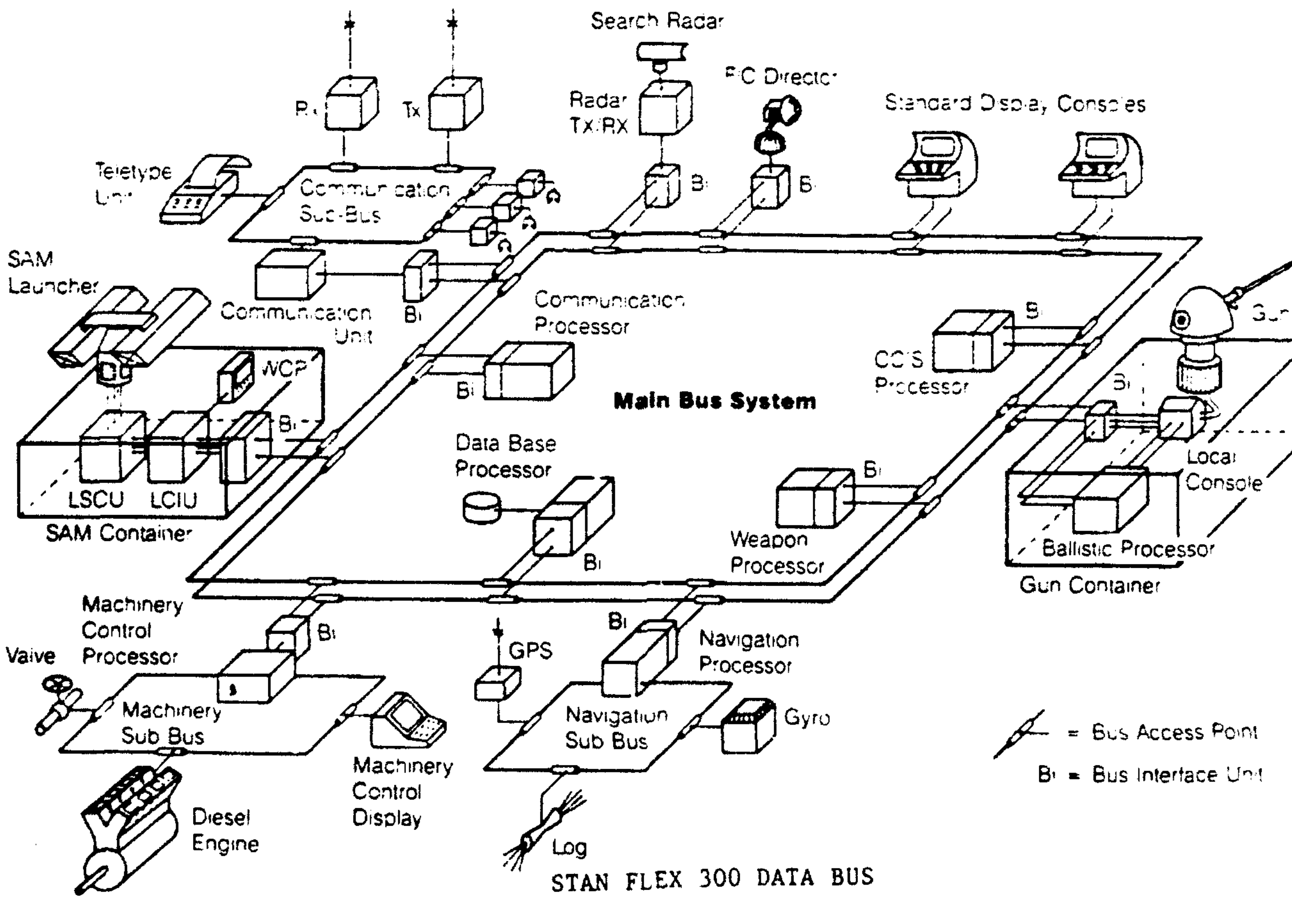
STAN FLEX 300 CONFIGURATIONS

FIGURE 13



STANDARD FLEX 300 CONCEPT

FIGURE 14



STAN FLEX 300 DATA BUS

FIGURE 15

definition for modular subsystems. However, changing requirements delayed the final approval of the program.

At this time, the program and its supporting future ship requirements are being reevaluated to focus the program on achievable goals. A key focus may be linked to common standards for local area networks and data bus architecture as well as standard weapon module and electronic module sizes and interfaces. The primary advantages of a cooperative R&D "modularity" project involving "standard interfaces" are envisioned to be as follows:

- Allied subsystems would be available to the U.S. Fleet and U.S. subsystems would be available to the allied fleets without the significant cost for major design developments - and with standard interfaces.
- Increased operability
- Reduced time of introducing new technology (U.S. or Allied)
- Increased technology sharing.
- Reduced life cycle costs due to improved testing , upgrade capability, and interchangeability.

In a recent article Secretary of Defense, Richard Cheney [17] stated,

"...With a declining defence budget, the US has the choice of engaging in co-operative programmes with its NATO and non-NATO Allies or of accepting less defence. ... The pursuit of co-operative research and development projects is an effective means of sharing the cost of modernizing our conventional defence capabilities while at the same time fielding standardized equipment that is so important to allied combat capability. ... The DoD seeks to achieve improved warfighting capabilities as well as cost savings by co-operating with its Allies in the development, production and follow-on support of military equipment. DoD's objectives for such armaments co-operation activities include:

- Propose co-operative research and development projects to the Allies to address critical deficiencies and inviting the Allies to propose such projects to the U.S.
- Acquire equipment already developed and fielded by our Allies, as an alternative to expensive US development programmes, when the Allied equipment meets US requirements and a US programme to meet our requirement is not already in development.
- Encourage our Allies to acquire equipment already developed and fielded by the US, as an alternative to their own expensive development programmes, when the US equipment meets their requirements and they do not have a programme already in development to meet those requirements. etc."

POINTS TO CONSIDER WHEN DISCUSSING PROS/CONS OF MODULARITY

- Ships are being designed for longer lives, up to 40 years.
- The number of ships and the shipbuilding budget are on the decline. Ships are increasing in cost because the weapon systems are more complex and costly. We need affordable ships that can counter the threat.
- With the increasing cost of weapon systems, consideration is being given to buying the basic ship, designing in "space and weight," and adding/upgrading some of the weapon systems in the future as funding becomes available.
- Combat systems and electronics are modified/modernized more frequently than the basic ship/propulsion/auxiliary/electrical systems.
- Conventional modernizations and conversions are costly; results of recent Navy studies indicated a desire to downgrade the role/mission of ships as they get older rather than to pay for costly modernizations, but that was when we were still building new combatants at an acceptable rate.
- There is increased interest in using data bus architecture (especially fiber optics) throughout our ships.
- We need to reevaluate our ship/systems cost estimating procedures. "Modular" (SSES/VPS/SEAMOD) ships will most likely be bigger and weigh more due to increased volume requirement (estimated at 5-8%) compared to conventional ships and Group 100 (Structure) will still be the largest and least expensive. However, weapons/electronic systems are becoming lighter, but more expensive. "Bigger"/"Heavier" ships don't have to cost more if you control what you put in them and how you fill up that extra volume.
- Life-cycle costing needs to get more than just "lip-service." Acquisition Managers need to be "graded" on life-cycle cost as well as the acquisition cost.

- What does industry think of packaging their products in modules? We need to convince them it is "good business."

- If International modularity/commonality can be accomplished, it will open up world markets that may now be closed or unprofitable.

PROBLEMS TO BE ENCOUNTERED

1. Resistance to change.

2. Unknowns - cost? risk? technical problems? (Fear of failure to meet cost, schedule, or produce a product.)

CONCLUSIONS

The following first three conclusions by Jack Abbott [1] in 1977 have not significantly changed in the 13 years that have passed.

1. SEAMOD facilitates rapid installation or exchange or both of combat system elements through the deliberate decoupling of the design/construction interdependencies of payload and platform. (Although the U.S. Navy has not proved this to be true, it does appear to be verified by the MEKO/FES system and the Royal Danish Navy's Stanflex 300).

2. The SEAMOD concept contemplates design and construction of ship platforms capable of receiving all of their combat system payloads (major armament system, sensor systems, and electronics) as modules. Included in the concept are hardware and software design considerations to facilitate the physical, functional and electronic integration of the payload modules.

3. This modularization capability will allow the Navy to:

(a). Simplify the acquisition, construction, and modernization of ship platforms and payloads.

(b). Hasten the introduction of new-technology weapons systems (payloads) into the fleet.

(c). Quickly convert the type and mix of combat system elements to counter new and changing threats.

4. The following benefits may be realized by using modularity:

(a). A greater number cf identical ships (common hulls) can be built using modularity, but easily allowing multi-mission capability. This approach could also reduce shipbuilding time and design and construction costs.

(b). The construction of the platform is independent of the combat system delivery time, allowing the combat system equipment to be delivered later and to be more "state-of-the-art".

(c). The outfitting period is reduced by the relatively late installation of pretested combat system modules, again reducing construction costs.

(d). Quality assurance is maintained through the assembly and testing of the modules under workshop conditions rather than under onboard conditions.

(e). Clear divisions of responsibility are maintained between the shipyard and the various weapons and electronics manufacturers allowing for better organized and more efficient testing.

(f). The availability of ships built in accordance with the modularity concept is expected to be significantly higher because of reduction of the periods spent in refit, repair and modernization. These periods are shortened through the reduction of secondary work required for system or equipment refit or repair.

(g). Mission change-outs can be undertaken more easily than with a conventional design. The old payload modules can be removed without structural cut-outs, and the new pre-assembled and pre-tested payload modules can be installed rapidly without requiring structural alteration to the ship.

5. CDR Jolliff in 1974 [5] concluded, " The obvious fact which comes forth from all of the paper studies is that ultimately only an evaluation at the hardware level by actually "doing it" can provide a sufficiently valid basis for assessment of the net worth of modularity in ship design."

The Sea Systems Modification and Modernization by Modularity (SEAMOD) or the implementation of the Ship Systems Engineering Standards in the Variable Payload Ship Concept is a major change from the present methods and policies for ship and combat system design and acquisition. It offers an affordable solution if we all work for it. But, it can only be accomplished if everyone wants it to work.

WHAT DO YOU THINK? - LET'S GO BUILD SOME "HARDWARE!"

REFERENCES

[1] "Modular Payload Ships in the U.S. Navy", J.W. Abbott, SNAME annual meeting paper #10, Nov 10-12,1977.

[2] "Design for Change - The Impact of Changing Threats and Missions on System Design Philosophy," ,CDR James Simmons, Naval Engineers Journal, April 1975.

[3] SEM Brochure,5-90, NWSC,Crane Indiana.

[4] Ship Production, Storch, Hammon, and Bunch 1988.

[5] "Modular Ship Design Concepts",CDR James V. Jolliff, USN. Naval Engineers Journal, October 1974.

[6] Strategic Sealift Program Information Booklet, 16 April 1985, OP 42 4626, ser 421/5U373580.

[7] "Modularity: Maximizing the Return on the Navy's Investment," John T. Drewry and Otto P. Jons, Naval Engineers Journal, April 1975.

[8] "USS SPRUANCE (DD 963) CLASS, Designed For Change - The Payoff is Now," CAPT John T. Collins, USN, Naval Engineers, April 1975.

[9] "SEAMOD Combat Systems For Advanced Platforms", CDR S.E. Veazey, USN Naval Engineers Journal, February 1978.

[10] "SEAMOD - A New Way to Design, Construct, and Modernize Navy Combatant Ships", Charles E. Lawson, Naval Engineers Journal, February 1978.

[11] "The Design of Variable Payload Ships", G.W. Broome Jr., D.W. Nelson, and W.D. Tootle, Naval Engineers Journal, April 1982.

[12] "The Construction of Variable Payload Ships," D.H. Thompson, Jr. and L.M. Thorell, Naval Engineers Journal, April 1982.

[13] Special Supplement on the Blohm and Voss MEKO 2000, "NAVAL FORCES" publication, undated (either 1987 or 1988).

[14] Naval Materiel Command, Denmark pamphlet on Standard Flex 300, text and editing by Hans Harboe-Hansen, undated (approx. 1988).

[15] Naval Forces, Vol 8, 1987, CAPT S.T. Petersen (now RADM and Chief of the Naval Materiel Command, Denmark), "The Outlook For The Royal Danish Navy."

[16] WARSHIP TECHNOLOGY, pp. 15-16, May 1987, "Armaments Exchange Modules for Multirole Standard Flex 300."

[17] "The Need for Co-operation", Secretary of Defense, Richard Cheney.

Hazardous Material And Hazardous Waste Management Within The Navy -The Time Has Come-

Kenneth M. Gladstone
Fleet Logistics Support Directorate
(SEA 04E)
Naval Sea Systems Command

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ABSTRACT

This paper discusses alternative strategies to satisfy the requirement for the life-cycle control and management of hazardous material acquired and used by the Navy. It challenges the logistics community to pool scarce and competing resources and forge new bonds of social action to solve common problems related to a more efficient and cost effective management of this now very important and burgeoning program.

INTRODUCTION

The significant and rising number of incidents of pollution, contamination and industrial accidents related to the increasing use of hazardous material and the resultant rapid expansion in the amount of hazardous waste have struck a social chord. Growing public awareness and governmental concerns, coupled with new economic realities, have become powerful forces. These forces are causing many military and industrial planning and operating specialists to rethink the use of hazardous materials and their impact on the hazardous waste stream generated by day to day operations.

This paper explores alternative strategies to satisfy the requirement for the life-cycle control and management of hazardous material acquired and used by the Navy. As logisticians, we must recognize and consider new environmentally based responsibilities in working with the acquisition program managers, life-cycle engineers and supporting staffs of the hardware oriented systems commands and the Naval Supply Systems Command. Government and private sector logistics specialists working together must challenge the precepts of conventional organizational structure, forge new bonds of social action and pool scarce and competing resources to develop a more efficient, cost effective and comprehensive hazardous material control and management program.

BACKGROUND

Responding to high priority issues and national concerns, the Navy has focused attention and resources on such special needs as:

- The removal of asbestos in plant, equipment and systems
- The cessation of ocean dumping and oily waste discharges at sea
- The elimination of hazardous waste dumping in landfill operations
- The reduction of stack gas emissions afloat and ashore.

Within the last two years, the Navy has begun development of a comprehensive program specifically aimed at the life-cycle management of hazardous material and hazardous waste. With this program still in its infancy, there is ample opportunity for the Navy and the commercial sector logistics community to work together to build the proper infrastructure for a healthy and vibrant program.Logisticians play a significant and pivotal role in the development and implementation of a successful hazardous material and hazardous waste management program within Navy and DoD. The traditional Integrated Logistics System (ILS) elements considered in systems design and development (including supply support; technical data; packaging, handling, storage and transportation; manpower, personnel and training; maintenance planning; configuration management; facilities; and computer resources) also apply to the subject of hazardous material and hazardous waste management. Our task is really a

matter of hazardous material life-cycle management, a concept well within the jurisdiction of the logistics community.

Yet, without the concerted effort of logisticians in government and private enterprise, the field of hazardous material and hazardous waste management is prey to the following problems:

- Rapid growth without proper direction
- Rapid cost escalation without effective cost control
- Rapid growth in competing centers of subject area expertise without benefit of demonstrated successes and failures
- Rapid development of incompatible technologies without establishment of a commonly based goals and objectives posture
- Slow development and placement of the checks and balances necessary for the successful implementation of a sound hazardous material and hazardous waste management program.

To the Navy's credit, the Environmental Protection, Safety and Occupational Health Division, Deputy Chief of Naval Operations for Logistics, issued a comprehensive policy and requirements planning document in June 1989 (OPNAVINST 4110.2). It established broad program management guidelines for life-cycle control of hazardous material and the management of hazardous waste Navy wide. This program definition is very specific at the activity level and clearly spells out the primary responsibilites for the platform and program sponsors, systems commands, other major headquarters and fleet commands and activity commanders. But, how the many program elements, policy guidelines, separate functional areas and levels of responsibility fit together, has not yet been fully addressed.

Herein lies the opportunity, not only for the Navy, but also for the other military services and contributing segments of the private sector. Together, we must flesh out the framework of acoordinated hazardous material and hazardous waste program to ensure that the following areas are properly examined:

- Planned direction in program management
- Established and well-defined cost control parameters
- Controlled industrial growth linked with well-defined inspections, licensing and reporting criteria
- Demonstrated subject area expertise based on licensing and certified testing
- Coordinated technological development
- Institutionalized checks and balances with systems for progress reporting and program quality assessment feedback.

DISCUSSION

Several key policy considerations and program goals establish the initial boundaries of the Navy hazardous material control and management program. These include:

- Reducing the hazardous waste stream by 50% by end calendar year 92 using 1987 as the base year
- Controlling all supply system entry and access to hazardous material by stock number
- Standardizing labeling for hazardous material
- Improving utility of the Hazardous Material Information System (HMIS) and accessibility by forces afloat and ashore
- Ensuring adequate personal protective clothing availability for handling hazardous material and hazardous waste
- Reducing or eliminating hazardous material presently in use in existing systems and equipments
- Reducing or eliminating the need for hazardous material in future systems and equipments
- Refusing acceptance of nonconforming shipments of hazardous material
- Identifying life-cycle costs for hazardous material during systems design and development
- Ensuring adequate training for personnel involved with hazardous material and hazardous wasteo-Ensuring hazardous material is used and stored in the minimum quantity to do the job.

These policy considerations and program goals focus on four principal program management areas of discussion:

(1) Acquisition Strategy

(2) Material Management

(3) Personnel Training and Safety

(4) Waste Disposal.

Acquisition Strategy: Effective and improved acquisition strategy is the key to long term hazardous material phase out. Modifying and restructuring acquisition policy, to encourage and stimulate the reduction and elimination of hazardous material, contributes directly to the posture of each of the remaining principal program management areas. Logisticians, including policy developers and implementors, working in concert with procurement and contracting specialists, must revamp the bid preparation, bid review and contract award processes to encourage industry to offer less hazardous or nonhazardous materials in systems design and development. Each of us must continuously prod specification writers and others to speed up changes in existing requirements to allow for and encourage the use of less hazardous or nonhazardous materials. Additionally, we can review and rewrite existing commercial specifications and introduce new commercial ones to use in lieu of outdated or otherwise inappropriate government specifications.

Offering prospective contractors incentives, such as greater weight applied in the technical ranking factors for reducing or eliminating hazardous materials in bid proposals, benefits both government and industry by:

- Stimulating competition
- Encouraging development of new products and processes
- Contributing to the reduction and elimination of hazardous materials
- Reducing potential hazardous product liability lawsuits
- Reducing both the economic (product) costs and social (environmental) costs.

Until the appropriate rules and regulations can be changed, logisticians, working with research and engineering specialists, must insist that current procurement packages provide relief from existing federal or military specifications mandating the use of hazardous materials, if less hazardous or nonhazardous material can meet the end use or functional requirement. Future contracting should consider special cash awards and bonuses for risk taking and experimentation leading to breakthroughs and alternative products and processes for incorporation during system design and development.

Initiatives are underway (a joint systems command level working group) to insert new language for hazardous material requirement matters in the statement of work, contract data requirements list and data item description documentation contained in the procurement requirements package. But, development and implementation of improved procurement packages Navy-wide takes time. Industry specialists who break out the life-cycle cost considerations for hazardous materials in systems design and development now will give their companies a competitive advantage. And those companies who incorporate redesign considerations based on feedback data received from the platform and program sponsors, insuring a reasoned and informed balance in end use, program requirements and system costs for hazardous material in the equipment or system operation and the maintenance plan, will retain their competitive advantage.

Because of increasing costs associated with hazardous material identified in the finalized operation and maintenance plan, we must insure to consider comprehensive ILS workups emphasizing the technical data package needs for personnel training and safety, packing and packaging, storage and shipping, handling and disposal requirements. Failure to adequately treat any of the mandatory integrated logistics elements satisfactorily in future contract proposals may be grounds for systems redesign or even project termination.

Government and industry need to reexamine the minimum unit of issue (each instead of dozen) and smallest container size (pint rather than gallon) to effect the necessary operation or maintenance action. Weighing considerations of cost (most economic order quantity) versus packaging size (one unit per box vice six), logisticians should strive for the smallest container size, rather than potential cost savings for buying in bulk, to reduce the quantity of hazardous material handled during a specific work function.

Just as segments of industry have introduced single serving packaged foods (canned soup) and single dosage medicines (cough syrup), government and industry should focus on the single use and measured use container sizing and packaging of hazardous materials. This will contribute to the reduction in maintained quantities of these troublesome substances. Innovation in packaging and package size is attractive, not only to government contracting, but also to private sector markets.Material Management: Perhaps the most visible of the four major management areas, material management affords an immediate opportunity to impact current hazardous material practices and procedures. As a start, all hazardous material used by the military, if not the entire federal government, should be catalogued and assigned a national stock number (NSN). This will establish a baseline to identify all hazardous material products in use by the

government and buffer direct purchase of new or alternative hazardous products by end users which may lack proper ILS consideration.

Including a special hazardous material identifier in the current stock number assignment, such as creating a new federal supply group and class hierarchy beginning with some unique supply (00__) or group (__99) designation, is a possibility. Improved and standardized labeling, reenforced by the use of standardized icons, could further assist in properly dealing with hazardous materials.

In the absence of uniform and consistent labeling and labeling information, a hazardous material identifier in the NSN would be a very simple, universally constant and easily controllable triggering device for item recognition. Such a scheme could be part of a structured chain of events to insure the proper use and handling of hazardous materials so identified. Identification in a numbering system would simplify the training requirement, negating the need to make everyone dealing with hazardous material an expert.

Instead, it would allow for the concentration in training of key personnel including supervisors, hazardous material coordinators, safety officers, industrial hygienists and others designated to oversee and assist in proper hazardous material usage. These people, in turn, are being specially trained to identify hazard types, safety precautions, protective clothing needs and the handling and disposal actions required. But, they need additional training in the use of material safety data sheets (MSDSs), management information system inquiries (the HMIS), government and industry telephone hotlines, personal protection equipment and enhanced safety, accident, spill containment and cleanup procedures.

Hazardous material labeling and the preparation of MSDSs have provided continuing grounds for controversy and debate. Despite many attempts and the presentation of varying proposals for standardization, simply too many differing and conflicting labeling requirements currently exist including:

- OSHA's Hazard Communication Standard
- Federal and Military Marking Standards
- Joint Military Directive for Air and Surface Shipment
- EPA Regulations
- Consumer Product Safety Commission Regulations
- Food and Drug Adminstration Regulations
- Bureau of Alcohol, Tobacco and Firearms Regulations
- Department of Transportation Regulations.

Because of these frequently conflicting and overlapping requirements, hazardous material labeling is a precipitous minefield involving simultaneously too little and too much information. And, the MSDSs are themselves (despite the intent of the law) wide ranging in their make-up, degree of specificity and overall content, size, length and the like. Though required, the MSDSs may not be received in advance of a pending shipment of hazardous material, or arrive concurrently with the shipment. In addition, there have been continuing delays and backlogs in screening MSDSs within the Navy prior to data entry in the HMIS. Often, these problems may delay or prevent the availability of important information contained in the MSDS to end users or others who need data about hazardous material, but, who may not have the proper documentation at hand.

While labeling and MSDSs may provide important backup and supplementary data, probably for some time, there will be continuing problems with labeling schemes and timeliness in receipt and processing of MSDSs. Yet, present day technology in bar coding (the Universal Product Code (UPC) used with food packaging) offers the opportunity to apply a similar methodology in the packaging of hazardous material. Current bar coding structures, magnetic strip data imprints and such containing labeling and identification information, could be applied to hazardous material identification. Parallels for such systems already exist regarding munitions tracking by wand and wand gun for such basic information as the manufacturer, lot number, the date of manufacture and date of expiration. Perhaps the existing Navy-wide Logistics Marking System (LOGMARS) could be adapted to meet the special needs of a hazardous material identification and inventory management tracking system.

Keying on product coding (or some other variation of bar coding) sidesteps continuing confusion over product labeling requirements and could reduce or eliminate problems associated with nonconforming shipments and their refusal at the first destination and beyond because of improper or missing labels and MSDSs. A partially or fully automated hazardous material receipt, tracking and inventory management system tied to product coding, rather than to paper receipt and validation, would increase program management efficiency and accuracy and reduce handling costs. Development and implementation of an industry standard bar coding system for hazardous material, with specific labeling and use data, could reduce or eliminate the need for the cumbersome, costly, paper driven MSDS.

Research and testing for less hazardous and nonhazardous material in future and existing systems and equipments are potentially lucrative and technologically challenging initiatives for both government and industry. Principal areas of concern focus on:

- Conducting reengineering and reverse engineering to eliminate the need for hazardous materials
- Designing and developing alternative products less hazardous or nonhazardous
- Simplifying the logistics support chain to deal with the hazardous component of the equipment or system (i.e., placing the hazardous material in a sealed unit not requiring direct handling).

Finally, focusing on depot and warehouse management, we should consider establishing regional or area depots whose sole function is hazardous material storage, handling and processing. For example, food stuffs have been singled out for storage and distribution at selected warehousing centers and bulk petroleum products have been segregated generally at special storage locations designed for product transfer by pipeline, truck or vessel. Similarly, special centers for most kinds of hazardous material would allow for concentration of the equipment and personnel resources necessary to properly manage such material at these locations and eliminate many of the duplicitous costs now incurred activity and system wide.

Logisticians can carry this idea one step further through the development of factory to base supply and delivery on demand as is done for many pharmaceutical, medical and food items. Shore based mess management facilities order and receive dry, fresh and frozen foods on daily or other periodic delivery schedules. Such treatment can be established for selected hazardous material, combining "push" and "pull" shipment from manufacturer or wholesale distributor to end user. This avoids the need for extensive, costly intermediate storage depots and provides a profit incentive to the producer and cost avoidance and cost reduction to the customer.

Personnel Training and Safety: Film libraries are growing with training films on hazardous material handling, storage and waste disposal. Middle and long range planning provides increased emphasis in hazardous material and hazardous waste subject matter for enlisted and officer basic and specialty training. Future contracts will require inclusion of appropriate references to hazardous material in drawings, technical manuals and other technical data provided as deliverables. These and other supporting initiatives are essential for effective training and safety program development. Industry logisticians, who recognize the need for more detailed and expanded training and safety related documentation in the life-cycle approach to hazardous material ILS considerations, may enjoy a competitive advantage, even with increased costs. Future contracting is being driven to call out this kind of training and safety information as separately packaged deliverables.

Specialty training for environmental and safety officers, the firefighters and others ashore, damage control persons, hazardous material coordinators and others afloat is already being conducted. This is important, but so too is the need to reach the ordinary sailor whose contact with hazardous material may be limited to simply moving a package from receipt on the main deck to stowage below. Or the task may be more difficult, requiring him to do a routine operating or maintenance action involving hazardous material. Efforts are ongoing by government safety, research and development specialists to devise a scheme to include standardized hazardous material handling and disposal information as part of the established shipboard maintenance program. But, with severe limits in spacing on maintenance requirements cards, much of the information must be abbreviated or coded, requiring the user to refer to other publications and reference material for a fuller explanation. The deckplate sailor and other occasional users need an easy-to-understand, compartmentalized hazardous material and hazardous waste "DOs" and "DON'Ts" primer. The Army issues periodic cartoon like maintenance and repair pamphlets (slightly larger than pamphlet size) for much of its ordnance and automotive equipment. Government and industry logisticians might consider designing a simple, easily digested pocket size guide for basic hazard types with straightforward DOs and DON'Ts and specific instructions on the places and people that can provide immediate help. Product and consumer markets already exist for such illustrated pamphlets that feature product and consumer safety, operation and maintenance information. Little innovation, if any, is required to also provide hazardous material handling and disposal information.

Increased emphasis needs to be placed on comprehensive discussion of spill, clean-up and accident procedures in the MSDSs associated with all new hazardous material orders and future receipts of existing hazardous material delivery orders. The time may come when manufacturers will be required to state, in the appropriate paperwork provided (MSDS, package labeling, product pamphlet and the like), that the emergency and spillcontainment handling procedures identified have been tested and certified as effective or represent the best available technology.

Personnel safety goes hand in hand with personnel training. To be effective, proper basic training techniques must include appropriate safety considerations. Unfortunately, safety considerations too often are treated only

briefly or not at all. Certain basic information concerning safety is attainable via:

- A warning message in a technical manual
- A safety placard mounted on the work space bulkhead
- A chart on the bulletin board in the work center
- A caution statement in the instruction book
- A sentence or phrase at the bottom of the label of the hazardous material container or packaging
- A demonstration depicted in a training film.

Frequently, what is missing is a detonator to energize the message content and make it come alive. For example, recruits in basic training are cautioned during rifle and pistol practice that even weapons loaded with blank ammunition can cause serious injury, even death, if fired at a live target at close range. When such a statement is made without visual and physical reenforcement, what do you think the typical reaction of a recruit would be? For those given a live demonstration, firing blanks at point blank range, the blast and damage effects shattering a dummy's body or splintering and breaking a plywood target, make a lasting impression. Just as firefighting and damage control training heightens individual cognizance and appreciation for the personal danger and risk, hazardous material safety training and safety awareness must be enhanced to include such activities as:

- Increased live exercise emergency first aid training for hazardous material accident victims emphasizing precautions to be taken by the emergency technicians treating such victims
- Greater emphasis on hazardous material emergency response drills ashore and afloat similar to fire and damage control drills including leakage, spillage and containment drills
- Greater emphasis on hazardous material related safety training as a separate deliverable in acquisition and procurement ILS considerations
- Increased recognition of the need to station emergency response team members and trained safety observers during certain operation and maintenance actions involving hazardous material similar to setting a fire watch during welding or other "hot" work
- Accelerated joint industry and government research to reduce the numbers of differing types of personnel protective clothing authorized, concentrating instead on a basic outfitting of gloves, goggles, boots, bibs, coveralls, masks, breathing apparatus and the like to do at least the vast majority of the jobs associated with hazardous material handling and disposal.

Industry and government logistics specialists, together, can help eliminate multiple and differing requirements for hazardous material handling and safety training. In most cases, separate training and safety requirements for commercial and government use are wasteful and generate unnecessary increased costs. They may contribute to confusion and even error in the best way to deal with a particular event or circumstance. Industry training and safety standards that are readily adoptable for government use can reduce training program costs and may directly or indirectly increase product and process use and acceptability.

Waste Disposal: Clearly, practices, procedures and emphasis on new technologies that reduce or eliminate the need for hazardous material in the workplace aid in lessening the waste management and disposal problems. Every reuse or recycling of excess or unneeded hazardous material further reduces the waste stream. Working with the minimum amount of hazardous material necessary to effect an operation or maintenance action and working carefully so as to minimize the chance for spillage, leakage or accident, are also contributing factors reducing the generation of hazardous waste.

Another contributing factor is product shelf life. Too often, hazardous material becomes a candidate for disposal as waste simply because it exceeds the expiration date for use. We need to place greater emphasis on research and testing to establish longer shelf life utility and extend the shelf life through proper storage and controlled storage programs. Also, we must develop improved and simplified testing criteria to extend shelf life for unused product sealed in its original packaging that may still be fully usable or usable in specified alternative or other limited applications. Here, again, manufacturers who offer longer shelf life products or products with no shelf life restrictions may increase market share.Current efforts to reuse and recycle hazardous material should encourage development and expansion of:

- Local activity ashore/afloat recyling and exchange programs among work centers including work center sharing for hazardous material requirements and lead work centers for hazardous material storage and waste disposal preparation and processing
- Base level/area processing and recycling centers for hazardous material reducing amounts sent to the regional defense disposal activity (and the attendant

costs for repackaging, labeling, shipping, additional processing and, ultimately, disposal as waste).

Once a hazardous material becomes a hazardous waste and enters the disposal chain, logisticians and engineers must identify the steps to intervene, reduce, eliminate or neutralize the hazardous component at the earliest opportunity in the handling stages of the disposal process, for example, by:

- Adding or mixing with a neutralizing agent
- Subjecting to temperature controls (heat or cold)
- Suspending or mixing in a stablizing medium
- Processing (such as grinding up, encapsulating, distilling, evaporating, aerating or incinerating)
- Reprocessing to incorporate in new products such as paving and building materials
- Filtering, screening or separating the hazardous and nonhazardous components.

Recycling and recovery processes already established for such things as used oils and lubricants, certain low-level radioactive wastes and spent photo chemicals, must be expanded to include families of acids and bases, oxidizers and reducing agents, corrosives, sealants, waxes, insulators, adhesives, penetrants and the like which, heretofore, may have escaped consideration because of:

- Cost considerations alone
- Insufficient quantities in multiple and/or widely dispersed locations
- Lack of incentives
- Absence of regulationsoOver regulation
- Conflicts of interest.

For some recycled and reworked hazardous waste products, there is an easily identified economic cost return (reclaimed silver or recovered mercury). For others, there is a less readily defined social cost avoidance (lowered incidence of illness, reduced contamination of ground water). We must begin to consider such economic cost returns and social cost avoidances as part of the life-cycle cost management of hazardous material. Those in industry who can demonstrate how their hazardous material products can be recycled, rendered less hazardous before entering the hazardous waste stream or reprocessed to recover or offset part of the disposal cost have a distinct marketing advantage.

THE CHALLENGE

This paper only scratches the surface, piercing the leading edge of possibilities. Much ground work is already in place. Broad positive policy guidelines have been established to focus the attention, energy and talent of the platform sponsors and project engineers working with government and industry logisticians to address the problems of hazardous material and hazardous waste management. Now, it is up to us to take the lead to fashion the disciplined structure for a comprehensive life-cycle management program for hazardous material management. We must become environmentally oriented logisticians. We must insure that the same ILS planning for equipment and system hardware support is applied to the hazardous materials which may be embedded in the system's design and required for its proper operation and maintenance.

For new and emergent systems, the introduction or proposed continuation of specified hazardous materials must be vigorously questioned. We must attempt to reduce or eliminate their presence with reasoned consideration for any resultant increased cost or loss in equipment or system performance capability. For existing systems, the task is even greater and more urgent. We must reexamine the logistics chain in its entirety, probing for advantages and opportunities to intervene and substitute less hazardous and nonhazardous materials, new practices and new procedures without causing unacceptable loss in supportability, operability or efficiency in the fielded equipment or system.

The opportunity, the really exciting challenge for all of us, is to thoroughly reexamine the existing conventions governing the way we ply our trade, including such factors as:

- Item Identification: a new federal supply group/class table in the NSN, improved and standardized labeling, bar coding
- Packing and Packaging: minimum quantity/size and single use packaging
- Storage and Warehousing: specialty depots exclusively designed for hazardous material storage, handling and distribution
- Transportation: new strategies to minimize shipment, reshipment and material handling and direct delivery to end users

- Training and Safety: greater emphasis in dealing with hazardous materials and hazardous waste using "hands on" exposure

- Information Exchange: increased lines of communication and types of feedback loops for both emergency query and routine information transfer (telephone hotlines, computer bulletin boards, expanded management information systems tie-ins, newsletters)

- Item Reuse and Recycling: increased excess product availability awareness emphasizing reuse and recycling in place

- Item Disposal: increased awareness of both the economic and social costs focusing on prudent alternatives.

For hazardous material and hazardous waste management within the Navy, the time has come for government and industry to recognize the need for a new ILS element, hazardous material control. We must apply this new element in all ILS planning and life-cycle management considerations for new systems and equipment design and development. And, we must reexamine the applicability of the already established family of ILS elements to hazardous material operations, maintenance management and waste disposal actions in existing equipment and systems.

BIOGRAPHY

Mr. Gladstone has B.A and M.A. degrees in Political Science and an M.P.A. in Environmental Policy. He is a former Naval Officer, now a Supply Corps Captain serving in the Naval Reserve. With over twenty-six years combined military and civilian experience within the DoD (Navy, Marine Corps, DLA, OSD and temporary assignments with Air Force and Army activities), he is well versed in military logistics with special emphasis on oil pollution, spill containment and hazardous material management.

Mr. Gladstone is presently a senior program analyst and the staff environmental specialist for the Fleet Logistics Support Directorate, Naval Sea Systems Command, Washington, D.C.

COMPUTER-AIDED ACQUISITION AND LOGISTICS MANAGEMENT SYSTEM (CALMS): MAKING LOGISTICS EASY FOR THE ENGINEER

Thomas J. Gaglione
CALMS Program Manager
NAVSEA 04PA2

Barbara A. Young
Computer Systems Analyst
NAVSEA 04PA2D

Steven Weinstein
General Engineer
NAVSEA 04PA2C

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ABSTRACT

The Computer-aided Acquisition and Logistics Management System (CALMS), is a PC-based Integrated Logistics Support (ILS) software program which manages queries and requests for logistics and acquisition data in a paperless fashion. CALMS will assist engineers, logisticians and acquisition managers in identifying, understanding, obtaining and managing proper life cycle logistics support and required documentation for their program. By utilizing an ILS expert system approach, CALMS will optimize current logistics policy and procedures, identify program specific requirements, provide ILS strategy, analyze user's decisions and provide appropriate alerts to scheduling impacts and timing difficulties. CALMS' functionality is that of a logistics process identifier, planner, scheduler and manager. It is designed to automate the:

- **Life cycle ILS process**
- **Acquisition of logistics**
- **Management of logistics**

Ship Program Managers (SPMs) and life cycle Systems and Equipment Managers, including engineers, acquisition managers and Logistics Element Managers (LEMs), will have available a fully automated, systematic and integrated tool designed to support the life cycle planning and implementation of their ILS program. This includes the development and maintenance of all required life cycle ILS documentation (e.g. ILS Plans, Configuration Management (CM) Plans, Navy Training Plans (NTPs), etc.), life cycle costs and funding plans (e.g. Logistics Requirements and Funding Plans (LRFPs) or Life Cycle Cost (LCC) Plans), and required contractual documents (e.g. Statements of Work (SOWs) and Contract Data Requirements List (CDRLs). Additionally, CALMS' expert system approach and logic oriented questions utilizing an automated tailoring technique, provide sufficient advice to responsible managers in making difficult and time consuming programmatic and scheduling decisions.

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

ACAT	Acquisition Category
Ao	Operational Availability
CALMS	Computer-aided Acquisition and Logistics Management System
CALS	Computer-aided Acquisition and Logistics Support
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CD/V	Concept Demonstration/Validation
CE/D	Concept Exploration/Definition
CM	Configuration Management
DID	Data Item Description
FME	Functional Matter Expert
FRP/D	Full Rate Production/Deployment
FSD	Full Scale Development
HM&E	Hull, Mechanical, and Electrical
ILSMT	Integrated Logistics Support Management Team
ILS	Integrated Logistics Support
IOC	Initial Operational Capability
IS	Information Systems
LAN	Local Area Network
LCC	Life Cycle Cost
LCM	Life Cycle Management
LEM	Logistics Element Manager
LRR	Logistics Readiness Review
LRFP	Logistics Requirements and Funding Plan
NAVSEA	Naval Sea Systems Command
NDI	Nondevelopmental Item
NTP	Navy Training Plan
OPEVAL	Operational Evaluation
OPNAV	Office of the Chief of Naval Operations
POM	Program Objectives Memorandum
PPS	Post Production Support
PR	Procurement Request
QA	Quality Assurance
RMA	Reliability, Maintainability, and Availability
SOW	Statement of Work
SPM	Ship Program Manager
WAN	Wide Area Network
WSAP	Weapon System Acquisition Process

BACKGROUND

NAVSEAs mission is to design, procure and support the Navy's surface ships, submarines and associated ships and weapon systems. This paper is concerned about the support of NAVSEAs acquisitions. More specifically, this paper is concerned about the type of tools that need to be developed to enable the logistics and engineering disciplines to become partners in the concept known as "systems engineering". Program offices spend hundreds of hours reviewing hundreds of instructions across 18 logistics and logistics related disciplines to identify what type of logistics support program is adequate enough for their particular program.

The ILS Procedures Manual for Systems and Equipment (October 1989), and NAVSEA Instruction 5000.39 (March 1988), were developed to do some "forced integration" between logistics elements and major program acquisition events. However, legislation of policy alone will not ensure this. Policy and procedures to properly and effectively integrate logistics engineering with the design process are at best difficult to define and overly complex. Engineers and program managers have a difficult challenge ensuring that proper logistics support requirements are planned, programmed, budgeted and acquired concurrent with ship, ship systems, weapons, and combat system development, acquisition and modernization actions. As noted above, managers are found sifting through hundreds of independent documents in order to map out a satisfactory logistics program. The numerous hours and funds expended in this effort sometimes end with poor results and the failure of the logistics program to meet and satisfy its target logistics objective(s) and ultimate certification goal.

This paper will discuss a method by which we can utilize software programs to assist us in a systems engineering approach to unite the logistics process with the engineering process more effectively than we have done in the past. CALMS is designed to help identify and ensure that the proper and minimum logistics requirements are considered in the logistics strategy, the logistics planning documents and specified in the logistics portion of the contract. CALMS, however, cannot replace good management, sound judgement and timely decisions. It can assist in providing information during the process so the user can work through the process more efficiently and effectively.

The NAVSEA ILS Procedures Manual, NAVSEA S0300-BD-PRO-010/020/030 (Volumes I, II and III) was developed to identify and document the NAVSEA ILS process and provide the "what, when, how and why" guidance to systems and equipment engineers and program managers within the Command. This reference document is embedded into CALMS. CALMS further specifies "when" the ILS Procedures Manual identified logistics events must occur. The ILS Procedures Manual structure is illustrated in Figure 1. This single source of information addresses all ILS functional elements and selected related disciplines. The objective was to strengthen, streamline, standardize, and consolidate all NAVSEA life cycle ILS procedures into a single self-contained document in order to assist engineers and managers in acquiring and sustaining the necessary logistics support for their cognizant systems and equipment. The procedures in the manual were developed by each NAVSEA ILS functional element manager whose respon-

sibility involves developing and maintaining Command level ILS policy and procedures. As shown in Figure 2, the CALMS initiative was designed to capitalize on these established procedures and their application.

As an automated decision support tool designed to define a program's total ILS requirements, CALMS' intention was to utilize an expert system approach with respect to the identification, planning and management of logistics. It was also the intent to become as "modular" as possible in an effort to produce a variety of documents across 18 disciplines which support the program office's chosen logistics support strategy.

AN EXPERT SYSTEM APPROACH

CALMS uses an expert system approach in its execution and functionality. (See Figure 3 for a CALMS functional overview). What is an expert system approach? First, the CALMS program has been developed using the following methodologies: (1) Its data bases are composed of widely known facts; (2) these facts are contributed by NAVSEA's own logistics experts; applying rules of good judgement, sound reasoning, and intelligent "best estimates" drawn from a base of relevant historical information and input.

Second, the system user may access the system to assess status of an activity or problem, and, thus, receive probable determined courses of action and/or decisions that may be based on facts, rules, and data resident in CALMS.

CALMS data has been validated through interaction with "subject matter experts". The result is a computer program with a great deal of "intelligence" and credibility given its data bases reflect the knowledge and experience of its users.

CALMS is "expert-like" in that it will be useful in avoiding and/or resolving complex problems requiring extensive human expertise and judgment. CALMS was developed to be especially applicable to logistics planning and management. In these areas the logistics domain is data intensive and impacted by a number of logistics elements, a large volume of historical data, and the need for information, not all of which is always available in real time. CALMS helps in pulling together many interrelated and complex procedures and processes by means of which the NAVSEA shore establishment and Fleet support activities attempt to maintain ships and systems in consistently high states of readiness.

Many definitions abound today concerning what does or does not constitute an expert system. The term "expert system approach" is applied to CALMS because it will assist users in achievement of higher levels of performance and response time due to on-line access to data. It would not be wrong to categorize CALMS as a decision support tool utilizing an "expert system approach" to its management of data and information.

CALMS FUNCTIONAL OVERVIEW

CALMS begins to tailor general logistics procedures, schedules, strategies, milestones, events, actions and planning documents as the user identifies the systems' or equipment' unique and specific program information. General program information such as nomenclature, program manager and office codes can be integrated with other CALMS application modules so that when this data is input the first time, it will be carried through to all other automated documents (i.e. one-time-update of logistics data found in more than one document). The user is then taken through a series of expert designed questions and is asked to define or select program specific parameters which will have a major impact on established ILS requirements, documents and schedules. Examples of parameters addressed include the applicable program Acquisition Category (ACAT), developmental or non-developmental item (NDI) status, system or equipment commodity group or type (e.g. Hull, Mechanical and Electrical (HM&E), Ordnance, Electronics or some combination thereof), life cycle phase, major milestone decision dates and others. The expert designed questions are based on current NAVSEA and/or OPNAV logistics policy (e.g. instructions and directives). The NAVSEA ILS Procedures Manual for Systems and Equipment is the source document for the integrated milestone scheduling guidance. NAVSEA has topical data and functional matter expert's corporate logistics knowledge as its main drivers behind CALMS' initial strategy advisor default value programming.

This ILS information is stored and periodically updated by the responsible NAVSEA ILS functional element or related discipline manager. The questions structured around the ILS information help to modify and tailor acquisition program requirements through expert developed associations and relationships. The user's ILS strategy is formulated via a combination of logistics milestone GANTT charts. These ILS schedules cross over 18 disciplines, 400 milestone events, 2800 actions and between 200-400 instructions. Each disciplines events can be dealt with independently or all can be chronologically combined into a single strategy and schedule dependent on the user's specific acquisition program key events. Once this broad initial tailoring or universal level modeling is complete, other modules begin the initial generation, skeletal development and eventual final product generation of documents which support the program strategy and schedule. These additional CALMS modules, found under the document generation menu, include the SOW/CDRL Advisor, the ILS Plan Advisor,

the LRFP Advisor, a system generated "Tickler" report, and an ILSMT point of contact listing. In addition to the final tailored logistics schedule, plan or contractual statement, CALMS will provide the engineer, logistician and acquisition manager with a more streamlined and simplified identification of the necessary logistics processes, strategies, procedures and events found throughout the Life Cycle of his or her system/equipment. It was also designed to inform and assist them to develop and meet tailored target schedules and develop tailored logistics documentation to satisfy the minimum logistics requirements for the program. The CALMS program flowchart is shown in Figure 4.

CALMS PRIMARY FUNCTIONS

The CALMS program consists of three primary functions. All functions contain sub-functional operations. The three primary functions are as follows:

- ILS STRATEGY ADVISOR
- ILS DOCUMENT GENERATION
- EMBEDDED ILS POLICY AND PROCEDURES

THE ILS STRATEGY ADVISOR

The ILS Strategy Advisor is an automatic schedule generation tool which establishes the Weapon System Acquisition Process (WSAP) Key Events (i.e. milestone decisions, design reviews, OPEVAL, etc.) as the "system driver" for all logistics and logistics related events necessary to support the system or equipment under development or procurement. Table 1 is an example of Key Program events for all system and equipment ACATs in the Full Scale Development (FSD) Phase of the Acquisition Cycle. There are other Tables for other acquisition scenarios (although not documented in this paper). The durations given to the FSD Phase and each WSAP event itself comes from averaging NAVSEA historical data with respect to each area. To "initiate" a scenario, the user must add his program to the CALMS data base by answering program specific questions via the ILS Strategy Advisor sub-functional areas pertaining to "ADD/UPDATE PROGRAM DATA". This sub-functional area option is the starting point when setting up a CALMS acquisition program.

During the program set-up, CALMS automatically tailors its operations and data bases when the user answers acquisition oriented questions with respect to program specific parameters. Refer to Figure 5 for the ILS Strategy Advisor functional breakdown. This program set-up process is performed for each acquisition program. The Strategy Advisor option and sub-functional options allows the user to create and maintain data bases and run two basic reports for life cycle program management:

- PROGRAM SUMMARY STATUS REPORT – This report contains general acquisition program data and major acquisition program highlights.
- ILS SCHEDULES – GANTT and milestone charts in chronological sequence identifying key program events and associated logistics milestone events for 18 logistics and logistics related disciplines.

The system generated schedules from this module are program tailored WSAP Key Event and logistics milestone event "default values" initialized from CALMS embedded event relationships, dependencies and durations. The rules and logic that intrarelates and interrelates WSAP Key Events and logistics milestone events have been determined and identified for CALMS by cognizant Functional Matter Experts (FMEs) for logistics elements and related disciplines. Figure 6 illustrates the following within the Full Scale Development Phase of the Acquisition Cycle: (1) the relationships and dependencies among WSAP Key Events; (2) the relationships and dependencies between WSAP and logistics milestone events; (3) the relationships and dependencies among logistics milestone events and (4) the durations of logistics milestone events.

All WSAP and logistics milestone event durations are default values. The user has the opportunity to change any or all event durations. In fact, he also has the opportunity to add or waive events. The program is completely flexible in this respect. With a minimum amount of program data, you can create multiple logistics schedules and choose the one that best suites your program. Both rapid development or program extension scenarios can be accomplished using the ILS Strategy Module. WSAP events and logistic milestone events are initialized, changed, updated, waived, etc., from the ILS Strategy Advisor sub-functional areas identified as Key Program Events and Milestone Events".

The Milestone Events sub-functional option off of the ILS Strategy Advisor Menu will assist the CALMS user in developing a life cycle ILS milestone chart which is driven by the WSAP Key Events. CALMS can generate logistics milestone charts for 18 disciplines separately or in an integrated chronological sequence. Because event durations are built into CALMS for all events, the user can determine when a task has to begin in order to meet an ever changing milestone date.

CALMS is an automated version of the ILS Procedures Manual for Systems and Equipment, October 1989 (i.e.

supersedes NAVSEAINST 5000.39). The ILS knowledge in the CALMS program is therefore organized first by the Acquisition Phases as identified by the Weapon System Acquisition Process. The knowledge is then compartmentalized by logistics and logistics related disciplines as identified by the ILS work breakdown structure shown in Figure 7.

The Acquisition Phases identified in the CALMS program are Concept Exploration/Definition (CE/D) Phase, Concept Demonstration/ Validation (CD/V) Phase, Full Scale Development (FSD) Phase, Full Rate Production/Deployment (FRP/D) Phase and Post Production Support (PPS) Phase. For these life cycle phases, there are over 400 logistic milestone events and 2800 associated action events in the CALMS program. The WSAP key program events represent major happenings and determine start and stop dates (i.e. windows of time) for logistics milestone events. The combination of WSAP key events might be unique for a given program based on that program's scenario. This is where the flexibility built into the CALMS software is important. Again, "program specific characteristics" DRIVE or TAILOR the "logistics knowledge base" embedded into CALMS.

ILS DOCUMENT GENERATION APPLICATIONS

The ILS document generator portion of CALMS is depicted in Figure 8 and currently includes three document generator modules:

- The ILS Plan (ILSP) Module
- The LRFP Module
- The SOW and CDRL Module

Data that has been identified by logistic experts as common or universal to ILS documents has been determined, defined and entered into the CALMS program set up and expert shell. If data considered common or universal in application is to be changed, changing it in one module will also change it in all ILS documentation modules. This ensures the integrity of data generated from the program and allows for ease of data base maintenance.

THE ILSP MODULE

All NAVSEA acquisition programs are required to develop and maintain an ILSP. The requirements for an ILSP are provided in NAVSEA Instruction 5000.39 and the ILS Procedures Manual for Systems and Equipment. The ILSP module, as shown in Figure 9, of the CALMS program provides the capability to generate two major portions of the document, the text and events and milestones. The resulting ILSP can then be printed in a standard format stored on floppy disk. Review and update of the ILSP is eased by the capability of reloading the document data into the computer, entering only required changes and re-generating a new, updated ILSP. Data that is common or stored in the CALMS program appears in the ILSP document automatically. Changing that data in the ILSP Module automatically updates all other modules. The key program events and milestones programs are the same as those for the ILS Strategy Advisor. The schedule can be developed and maintained from either location in the program. The ILSP module produces the following outputs:

- ILSP Cover and Front Matter
- Table of Contents
- Text for all ILS Elements
- Key Program Events
- ILS Milestone Events

Some of the significant capabilities of the ILSP module are as follows:

- Self Contained Users Guide
- On-Line HELP Program
- Rapid and Easy Updating or Editing Capability
- Performs All Required Mathematical Computation for Ao
- Eliminates repetitive entry of Information
- Automatic Page Numbering of Document
- Optional List of Acronyms

THE LRFP MODULE

NAVSEA acquisition programs are required to develop LRFPs or LCC Plans in accordance with NAVSEA Instruction 5000.39 and the ILS Procedures Manual for Systems and Equipment. The automated LRFP Module was designed to assist NAVSEA program managers in preparing and documenting the total ILS funding requirements (by logistic element) for their acquisition program. Figure 10 illustrates this. Updates to the LRFP are based on program changes and made in conjunction with Program Objectives Memorandum (POM) submittals. The automated LRFP Module will provide NAVSEA pro-

gram managers with a standard logistics cost reporting format that:

- Is easy to use
- Provides Helpful Direction
- Converts the NAVSEA LRFP into the OPNAV Reporting Format
- Produces Paper Reports in NAVSEA or OPNAV Format
- Prepares the NAVSEA Formatted Data for the Transmission to the NAVSEA LRFP data base

In developing an LRFP, the user will first enter certain program identification information and other program unique data into the module. The user would then select the logistic elements applicable to the LRFP for the acquisition program. Financial data is entered for all applicable fiscal years and for each applicable milestone event. Financial data can be entered for as many as eight fiscal years. The LRFP Module will calculate all line totals, sub totals and grand total costs. These costs will reflect the life cycle financial requirements for the acquisition program. The following formatted reports can be generated by the LRFP Module from menu offered selections:

- NAVSEA LRFP Cover Sheet
- NAVSEA Logistic Element Summary Report
- NAVSEA Detailed Logistic Element Report
- NAVSEA Appropriation Report
- OPNAV LRFP Cover Sheet
- OPNAV Logistic Element Summary Report
- OPNAV Detailed Logistic Element Report

THE SOW and CDRL MODULE

The SOW and CDRL Module, as shown in Figure 11, is a menu driven system that, through a series of expert questions for a functional area, develops a tailored SOW and CDRL package for a specific system or equipment program. The output of the tailoring process can then be modified further for incorporation into the Procurement Request (PR). The CDRL package will specify the data or products to be delivered as specified in the SOW. The SOW and CDRL module will provide all the applicable ILS requirements for a certain life cycle phase of the program. The module uses two software programs, a word processor for text manipulation and a CDRL program designed to generate or modify CDRLs. In developing the SOW and CDRL documents, there are a variety of logistics elements or functional areas that can be selected. Each of these areas is further defined by certain information passed through the CALMS shell to the SOW and CDRL Module. This information consists of the life cycle phase, whether the system or equipment is a NDI, and other related information on the system or equipment. A series of questions is then asked and answered with respect to a particular logistics element or functional area.

The answers to these questions are then interpreted by the CALMS program with its embedded knowledge base. The program then builds a macro file to tailor the template SOW into a generic SOW which can be further tailored by the user. The program also interfaces with the CDRL component of the SOW and CDRL module. The CDRLs are stored in a relational data base in the same structure as the SOW component. Only those CDRLS applicable to the SOW being generated will be identified and developed.

EMBEDDED ILS POLICY AND PROCEDURES

The ILS Procedures Manual module, as shown in Figure 12, allows the user to access the NAVSEA ILS Procedures Manual (NAVSEA S0300-BD-PRO-010/020/030). In it's simplest form, CALMS is an automated version of the ILS Procedures Manual for Systems and Equipment with "built-in tailoring guidance, scheduling capabilities and document generation modules".

The primary purpose of the manual is to document, in a coordinated, integrated and simplified fashion, the complex process of acquiring and managing ILS for NAVSEA systems and equipment. The acquisition of logistics support must be performed in an integrated manner during the appropriate acquisition phase if the proper support for a newly delivered system or equipment is to be available when needed. A separate ILS Procedures Manual for ships is currently under development.

Today, if the NAVSEA engineer, ILS manager or acquisition manager wants to accomplish the goal of delivering the proper logistics support for his or her product, that manager must sift through hundreds of independent documents in order to map out a logistics program. Needless to say, this is close to an impossible task and certainly contributes to our continuing problems with logistics audits. Simply stated, we have just made it too complex to understand.

We believe part of the solution to this problem was the development of this single set of ILS Procedures organized first by acquisition phase, then by ILS element. This particular manual was the product of "Phase I" of our effort. These procedures should provide for each ILS manager, project engineer or acquisition manager a "road map" which enables successful and rational compliance with a seemingly inexorable chain of ILS related directives. "Phase II" efforts will produce updates of the manual which will make it as self-contained as possible. The "Phase II" document will incorporate as many of the independent documents as possible, thereby upgrading this "Phase I road map" into a stand-alone "how to" document which simplifies a manager's logistic tasks.

SOFTWARE AND HARDWARE REQUIREMENTS

CALMS was designed to use hardware and software that is generally available to most offices in the Command. Except for hard disk space requirements (20 megabytes), most of the following requirements have been determined to be readily available or accessible in most program offices:

- IBM AT or Higher (100% Compatible)
- 640K RAM (Free)
- 20M Hard Disk Space
- DOS 3.X
- WordPerfect 5.1
- Laser Jet Series II Printer (No Special Cartridges Required)

FUTURE PROGRAM ENHANCEMENTS

Near term enhancements of CALMS will answer the need for improved information sharing and decision making capabilities through the evolution of the existing CALMS PC stand alone program to multiuser Local Area Network (LAN) and then Wide Area Network (WAN) applications. Needs will further be fulfilled by providing the addition of numerous new logistic document generation modules.

Longer term future enhancements of CALMS will incorporate the above CALMS capabilities and knowledge data bases into next generation software languages and tools. New technologies applied will appear in the form of case tools, knowledge systems shells and 4th generation languages.

CONCLUSIONS

Two dozen NAVSEA program offices, or field activities in support of those offices, received the CALMS prototype. Most of those Beta Test Sites had limited use of an earlier information modeling version of CALMS (i.e. engineering developmental model). Much debugging has occurred since the early version of CALMS, but more important, the developers have come to realize that there is a real need for this kind of tool.

Whether you call CALMS an expert system or an automated decision support tool, it is designed to assist the acquisition office in identifying what logistics requirements must be considered for their program, when they must be considered, why they must be considered, and how to go about carrying out their accomplishment.

Much process identification, knowledge collection and knowledge modeling has gone into this effort and it is only the beginning. The alternative is to re-read the instructions, re-invent the process or pay someone over and over again to re-invent a cut and paste product for each and every program. The application of an automated tool like CALMS will greatly improve productivity and make more efficient use of dwindling resources.

ACKNOWLEDGMENTS

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George White, Jim Mellis, Bill Losa, Fred Oberman,
Mark Mclean,Tom Scanlon, John Schell, Pattie Domnissey,
John Depass, Paul Wright, Ron Serra, Thomas Kyriakakis,
Phil Hans

REFERENCES

[1] NAVSEA S0300-BD-PRO-010/020/030; ILS Procedures Manual for Systems and Equipment, October 1989.

[2] NAVSEA Instruction 5000.39; Acquisition and Management of Integrated Logistic Support for Ships, Systems, and Equipment March 1988.

[3] Systems Engineering Management Guide, Defense Systems Management College, second edition, December 1986.

[4] Draft DOD Directive 5000.1 Defense Acquisition Management Policy and Procedures, September 1990.

[5] Draft DOD Directive 5000.2, Defense Acquisition Management Policy and Procedures, September 1990.

[6] Draft DOD Directive 5000.2M, Defense Acquisition Management Documentation and Reports, September 1990.

TABLE 1

ALL ACATs – FULL-SCALE DEVELOPMENT PHASE

(TOTAL DURATION: 85 MONTHS)

	KEY PROGRAM EVENT	DURATION (MONTHS)	PERCENT OF TOTAL
1.	MILESTONE II DECISION	0	0.00 %
2.	AWARD CONTRACT FOR EDM	6	7.06 %
3.	PRELIMINARY DESIGN REVIEW	3	3.52 %
4.	CRITICAL DESIGN REVIEW	12	14.12 %
5.	TEMP UPDATED	10	11.76 %
6.	LOGISTIC SUPPORT FOR FACTORY TESTS VALIDATION	3	3.52 %
7.	START FACTORY TESTS	2	2.35 %
8.	COMPLETE FACTORY TESTS	3	3.52 %
9.	LOGISTIC SUPPORT FOR TECHEVAL VERIFIED	1	1.18 %
10.	START INSTALLATION FOR TECHEVAL	2	2.35 %
11.	COMPLETE TECHEVAL	15	17.65 %
12.	LOGISTIC SUPPORT FOR OPEVAL ESTABLISHED	2	2.35 %
13.	START OPEVAL	1	1.18 %
14.	COMPLETE OPEVAL	1	1.18 %
15.	ACQUISITION PLAN REVIEWED/UPDATED	1	1.18 %
16.	LOGISTICS PROGRAM DOC. REVIEWED/UPDATED	1	1.18 %
17.	PRODUCT BASELINE ESTABLISHED	1	1.18 %
18.	LOGISTICS ASSESSMENT (LRG/LRR)	1	1.18 %
19.	MILESTONE III.A DECISION (ALP)	4	4.71 %
20.	FOLLOW-ON TESTS EVALUATION (FOT&E)	12	14.12 %
21.	MILESTONE III.B DECISION	4	4.71%
		85	100.0 %

6 291 6

ILS PROCEDURES MANUAL STRUCTURE

DIVIDED BY ACQUISITION PHASE

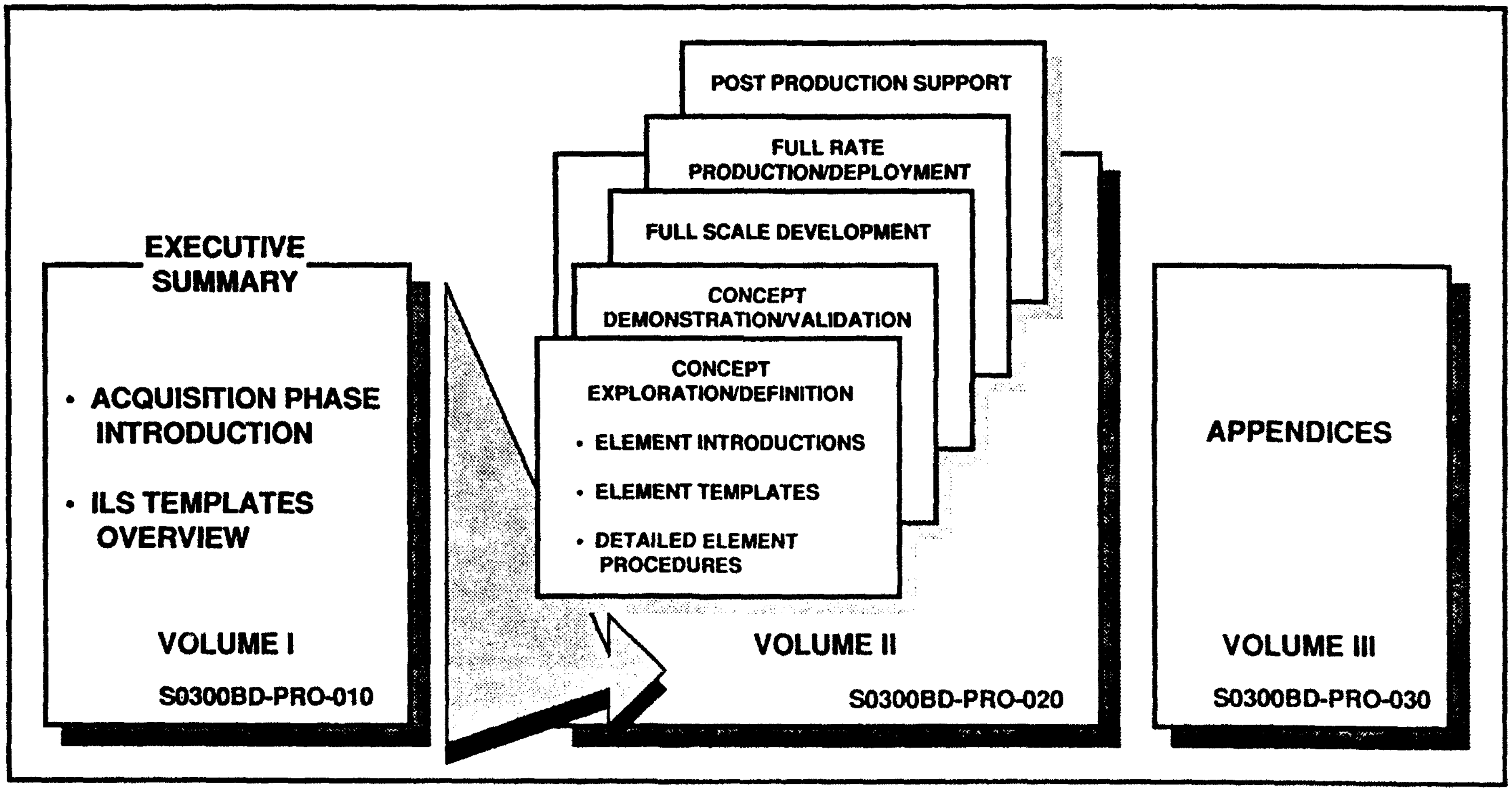
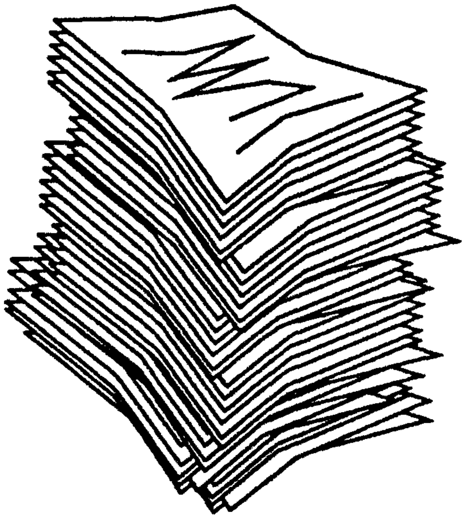


FIGURE 1

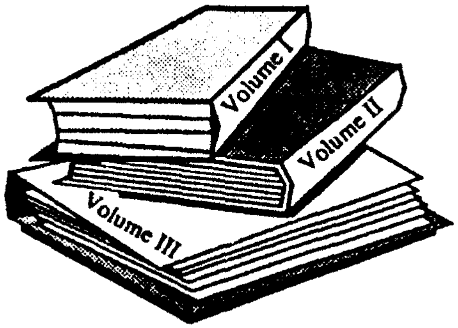
6 291 1

ILS EXPERT SYSTEM PROGRAM INITIATIVE

FROM:
200-400
INSTRUCTIONS



TO:
ILS PROCEDURES
MANUAL



TO:
AUTOMATED
DECISION SUPPORT
TOOLS

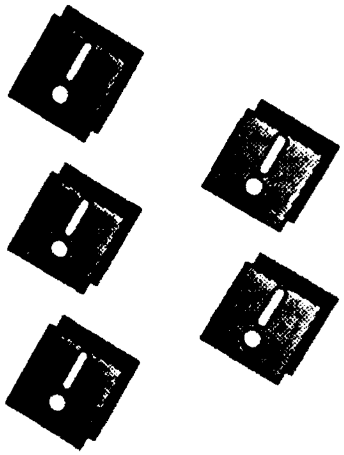


FIGURE 2

6 291.2

FUNCTIONAL OVERVIEW OF CALMS

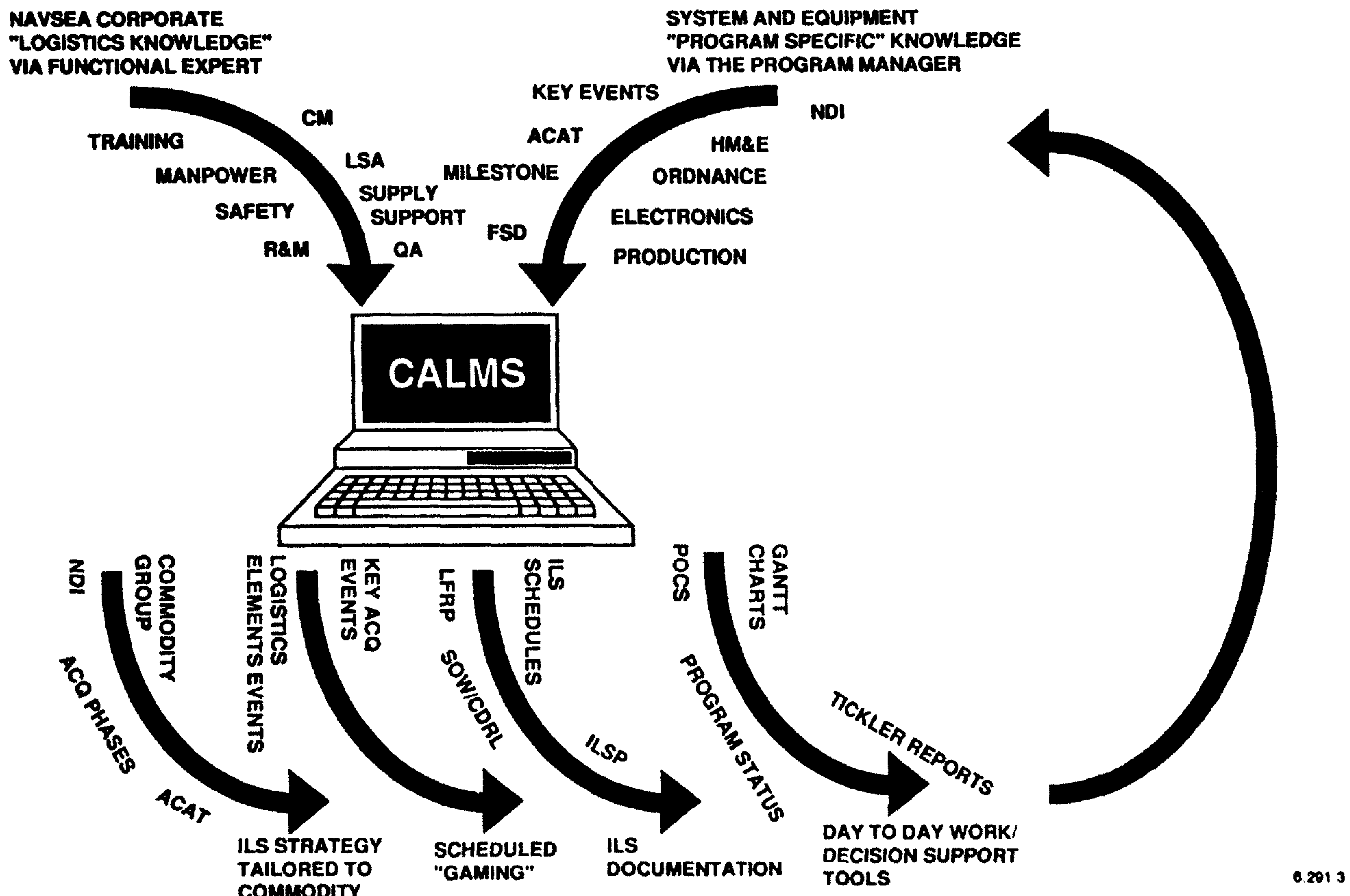


FIGURE 3

CALMS FLOWCHART

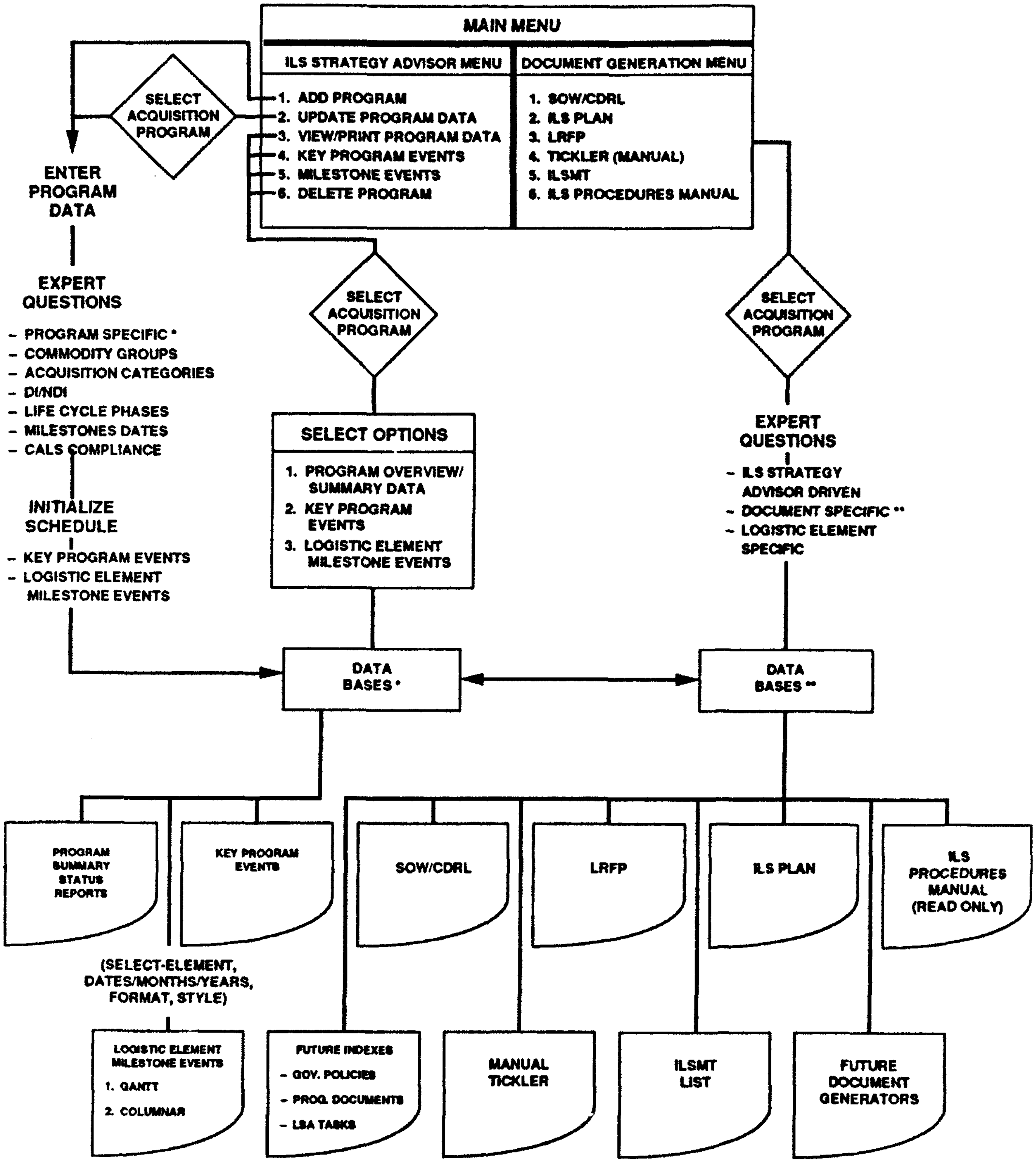


FIGURE 4

6.990.50A

ILS STRATEGY ADVISOR (PROGRAM SET UP)

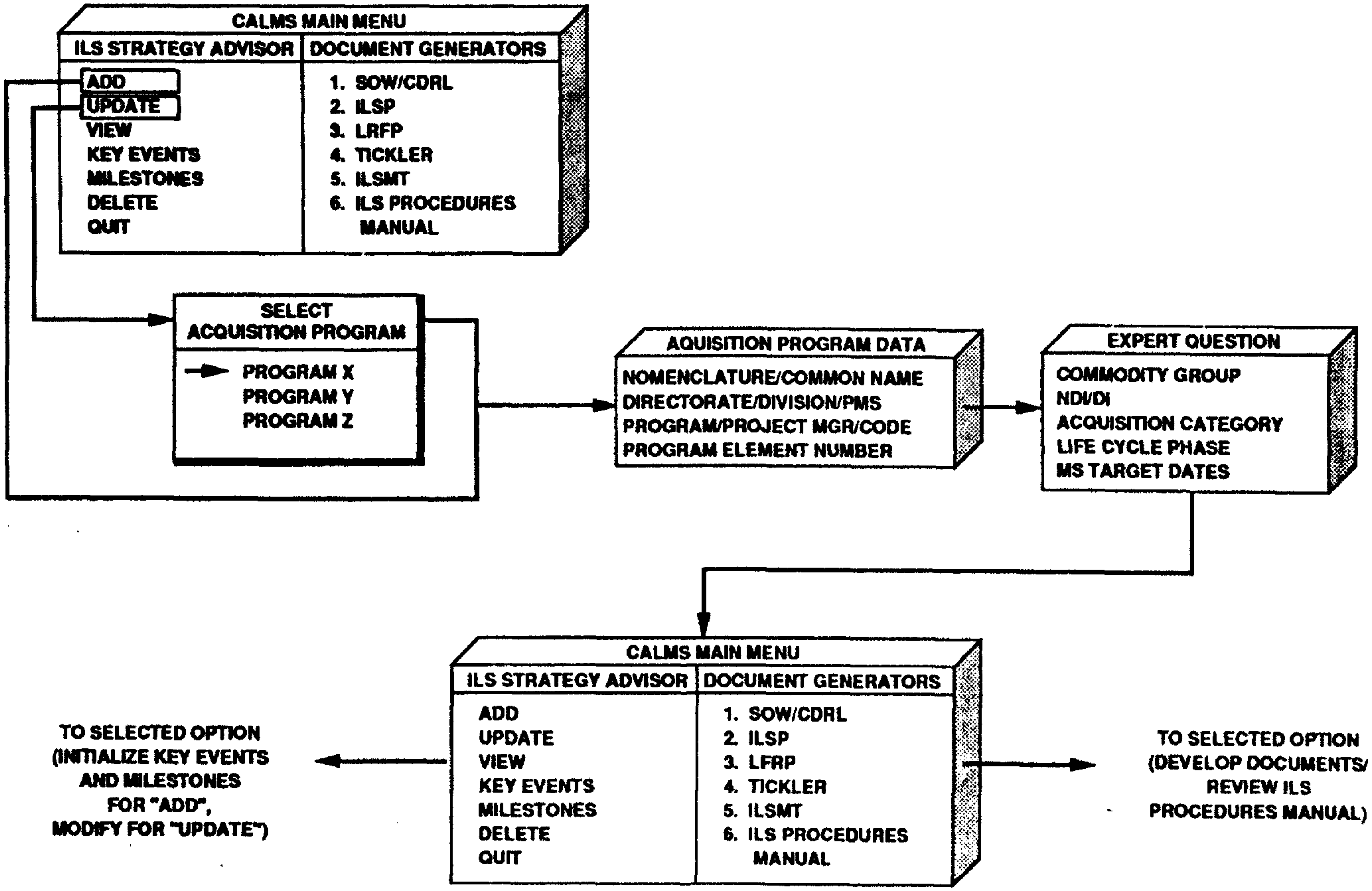


FIGURE 5

 8 291.19

KEY PROGRAM AND MILESTONE EVENTS CHART
(FULL SCALE DEVELOPMENT)

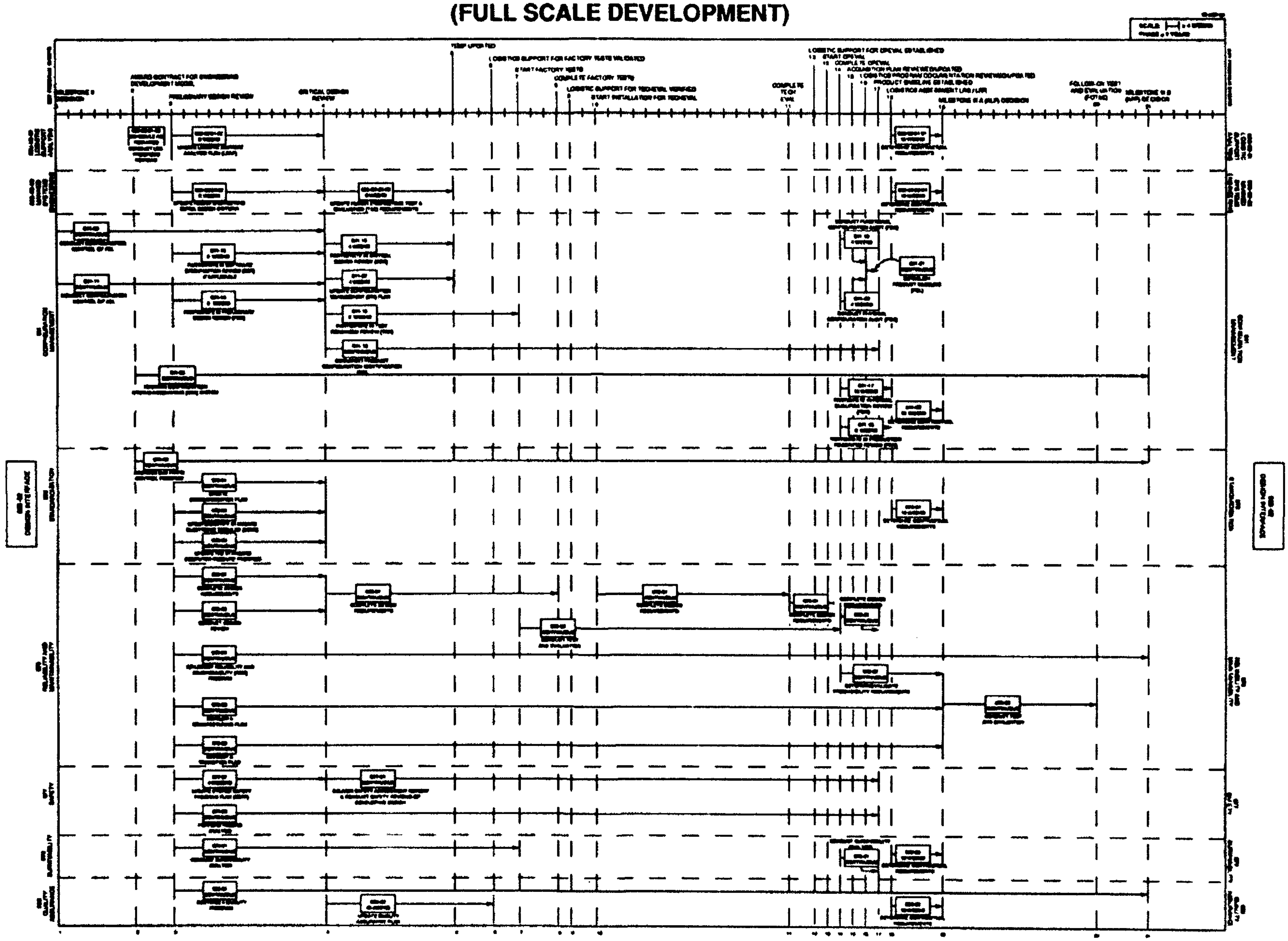


FIGURE 6

KEY PROGRAM AND MILESTONE EVENTS CHART
(FULL SCALE DEVELOPMENT)

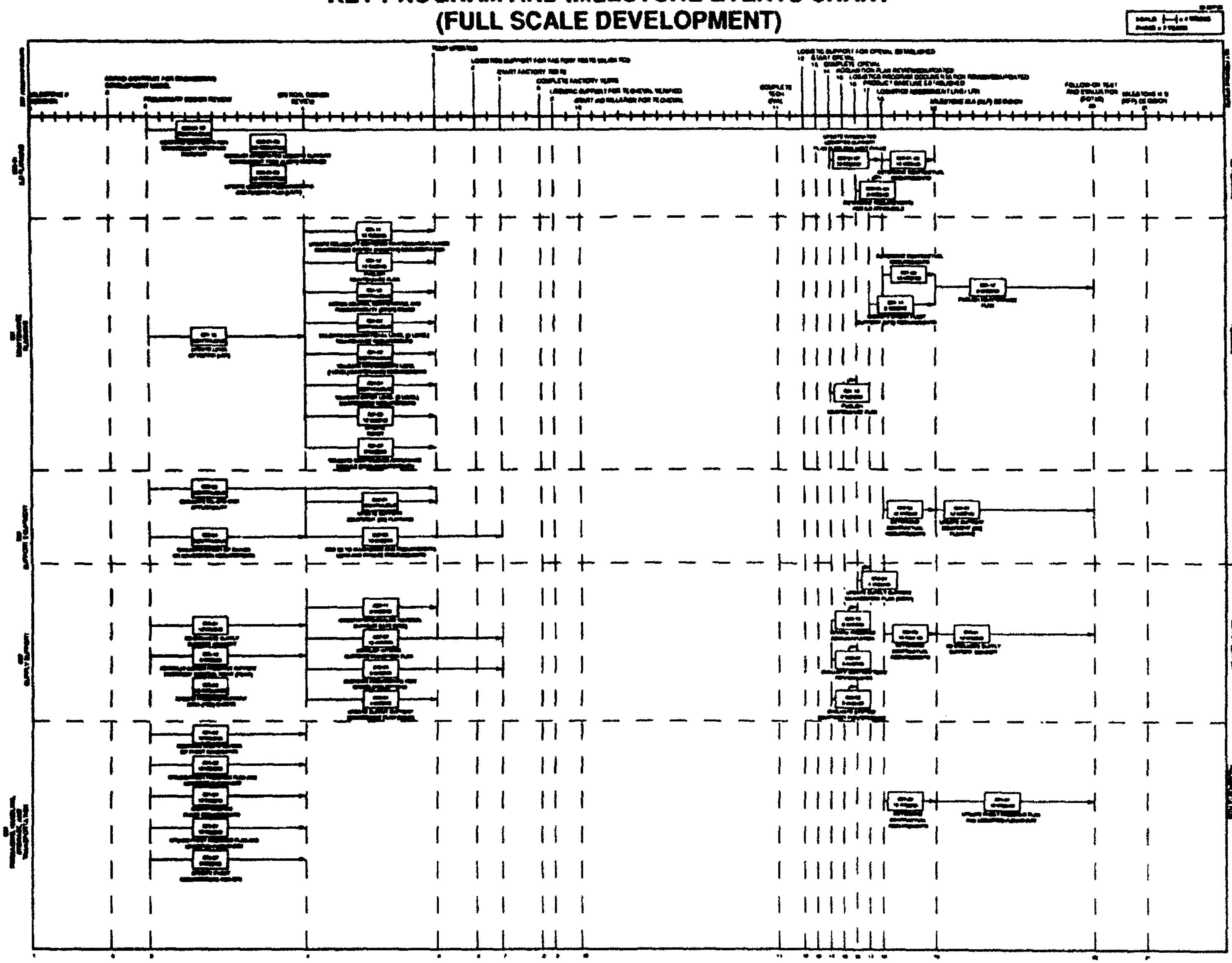


FIGURE 6

KEY PROGRAM AND MILESTONE EVENTS CHART
(FULL SCALE DEVELOPMENT)

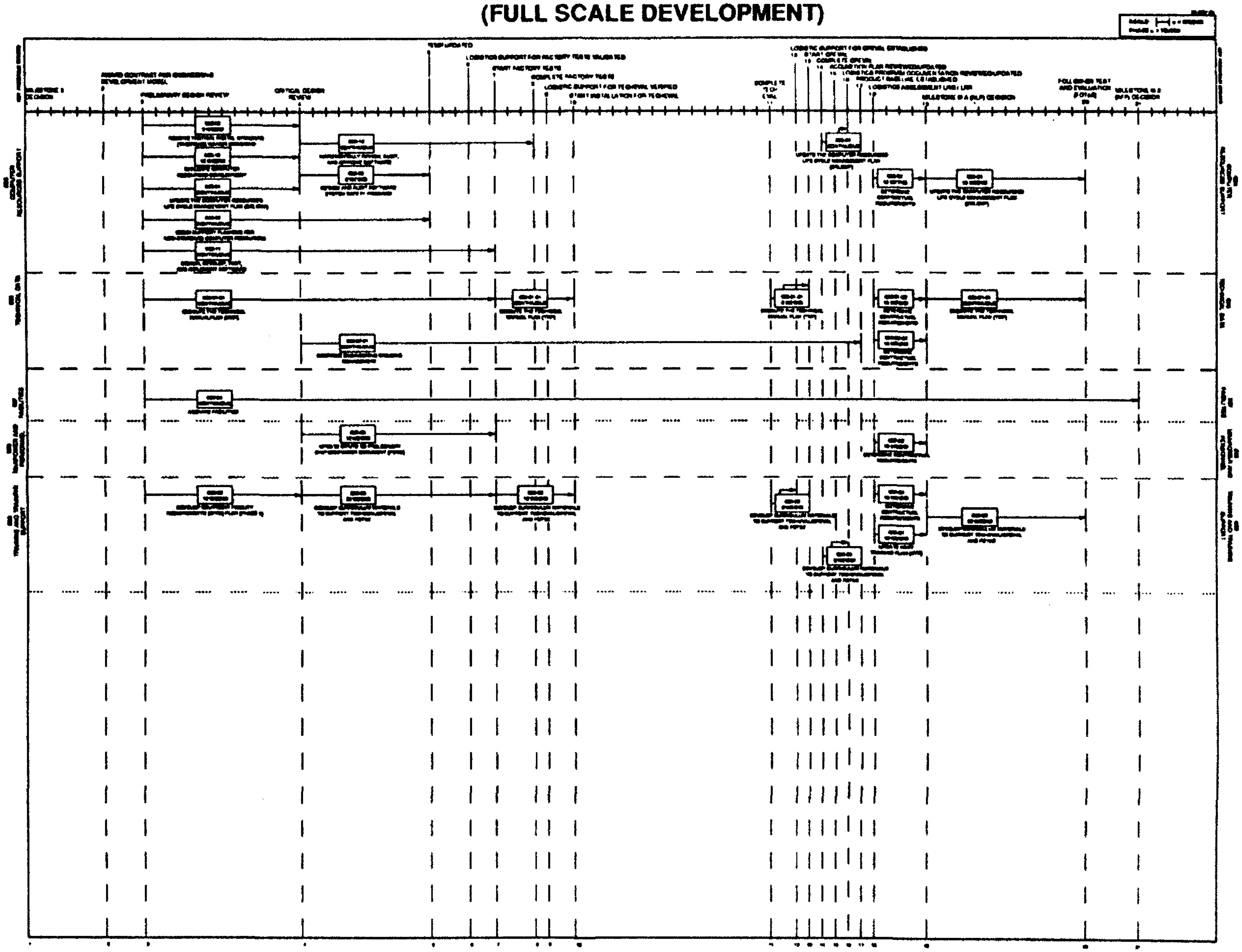


FIGURE 6

ILS WORK BREAKDOWN STRUCTURE

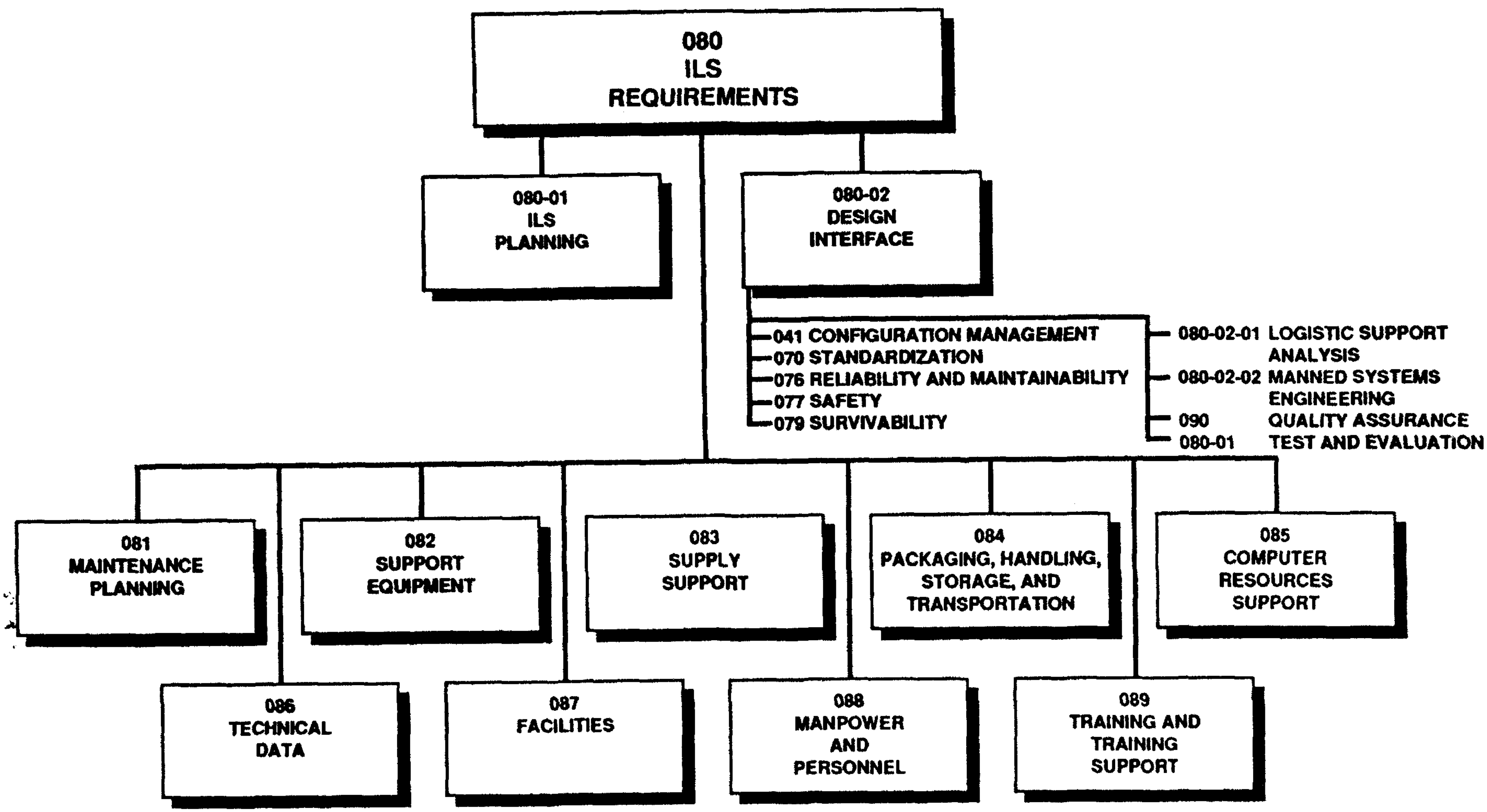


FIGURE 7

6 291 26

ILS DOCUMENT GENERATION FLOWCHART

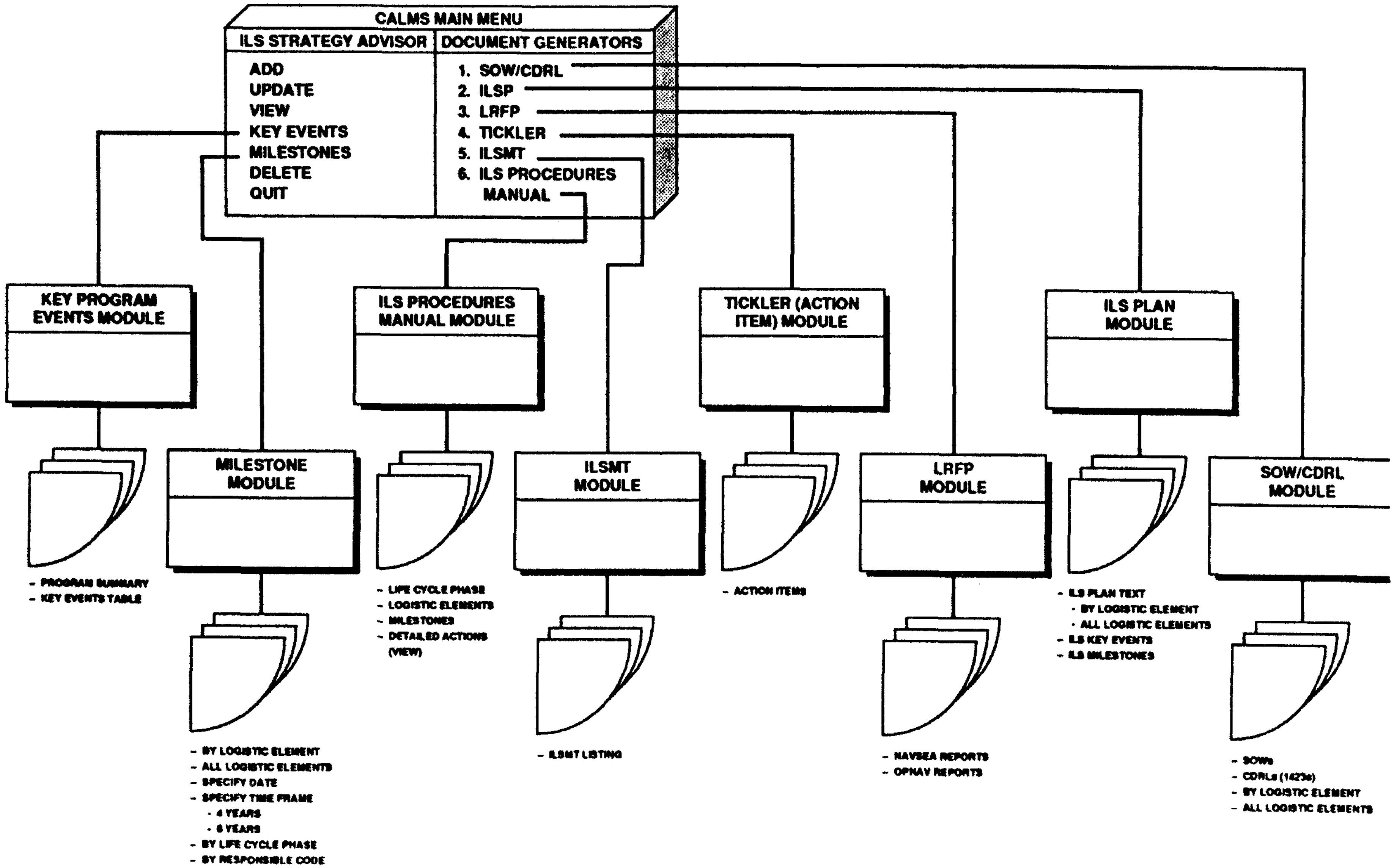


FIGURE 8

8 291 25

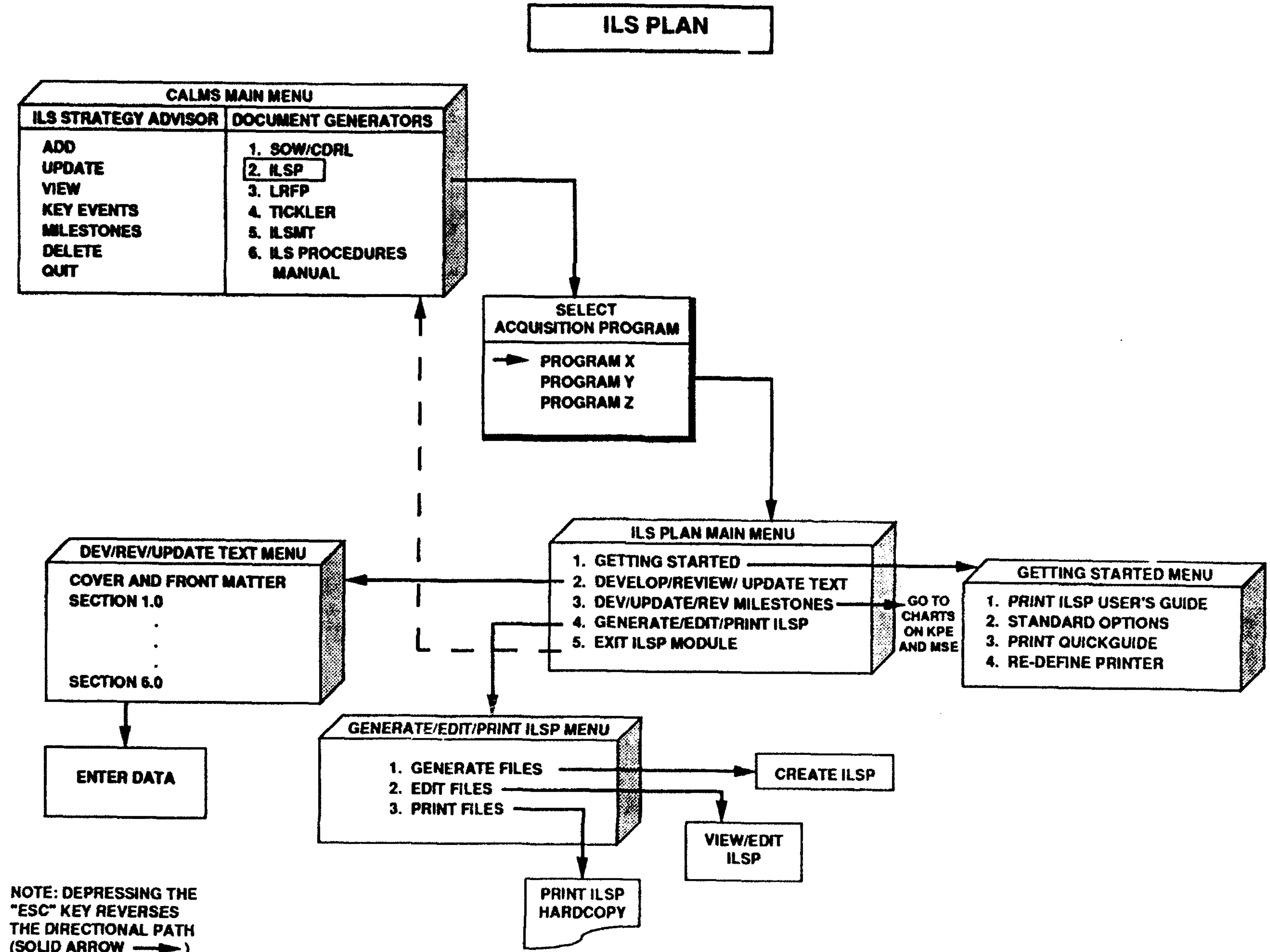
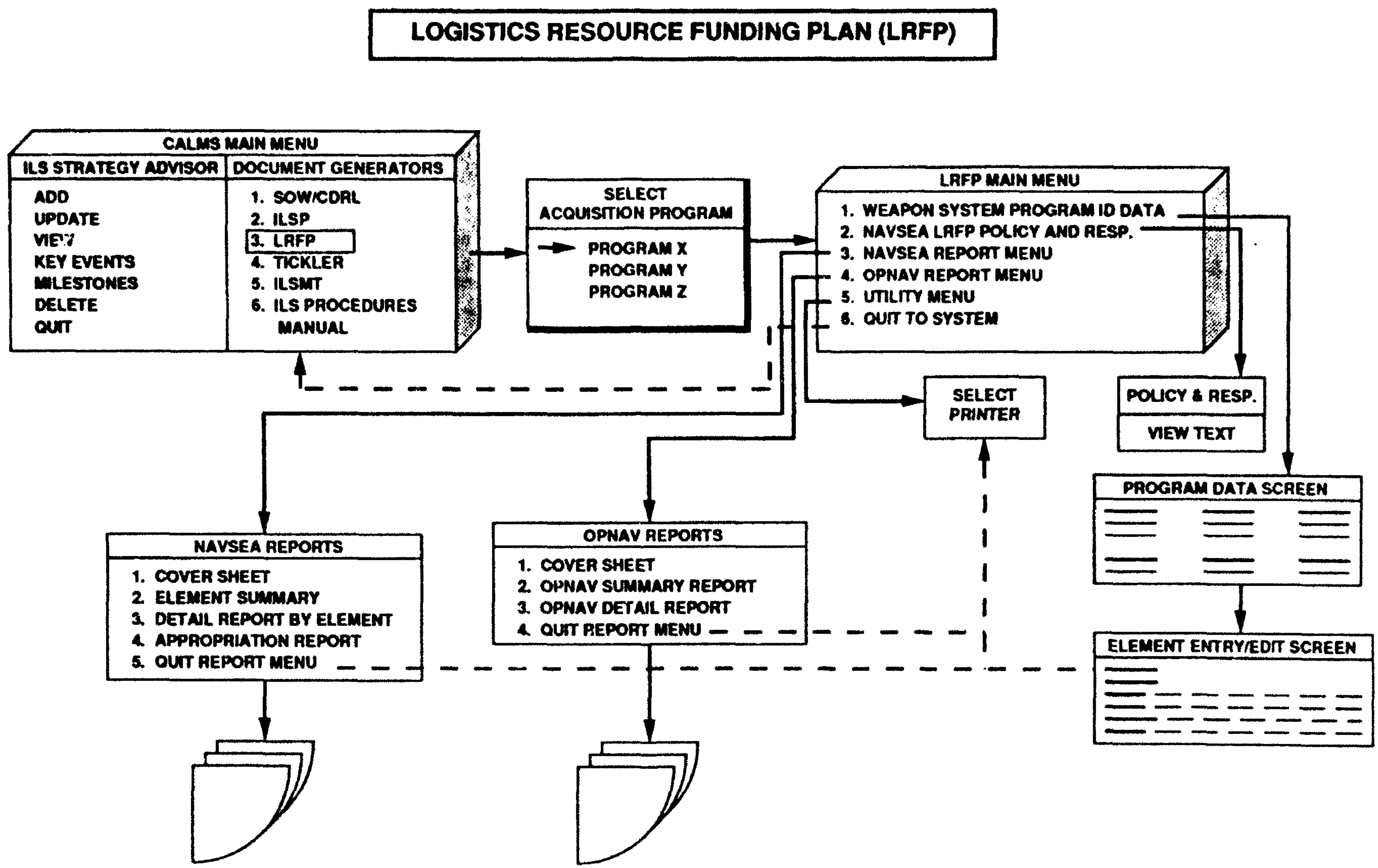


FIGURE 9

9 490 132/



LOGISTICS RESOURCE FUNDING PLAN (LRFP)
CALMS MAIN MENU
ILS STRATEGY ADVISOR
ADD
UPDATE
VIEW
KEY EVENTS
MILESTONES
DELETE
QUIT
DOCUMENT GENERATORS
1. SOW/CDRL
2. ILSP
3. LRFP
4. TICKLER
5. ILSMT
6. ILS PROCEDURES MANUAL
SELECT ACQUISITION PROGRAM
PROGRAM X
PROGRAM Y
PROGRAM Z
LRFP MAIN MENU
1. WEAPON SYSTEM PROGRAM ID DATA
2. NAVSEA LRFP POLICY AND RESP.
3. NAVSEA REPORT MENU
4. OPNAV REPORT MENU
5. UTILITY MENU
6. QUIT TO SYSTEM
SELECT PRINTER
POLICY & RESP.
VIEW TEXT
PROGRAM DATA SCREEN
ELEMENT ENTRY/EDIT SCREEN
NAVSEA REPORTS
1. COVER SHEET
2. ELEMENT SUMMARY
3. DETAIL REPORT BY ELEMENT
4. APPROPRIATION REPORT
5. QUIT REPORT MENU
OPNAV REPORTS
1. COVER SHEET
2. OPNAV SUMMARY REPORT
3. OPNAV DETAIL REPORT
4. QUIT REPORT MENU
6 291 24

FIGURE 10

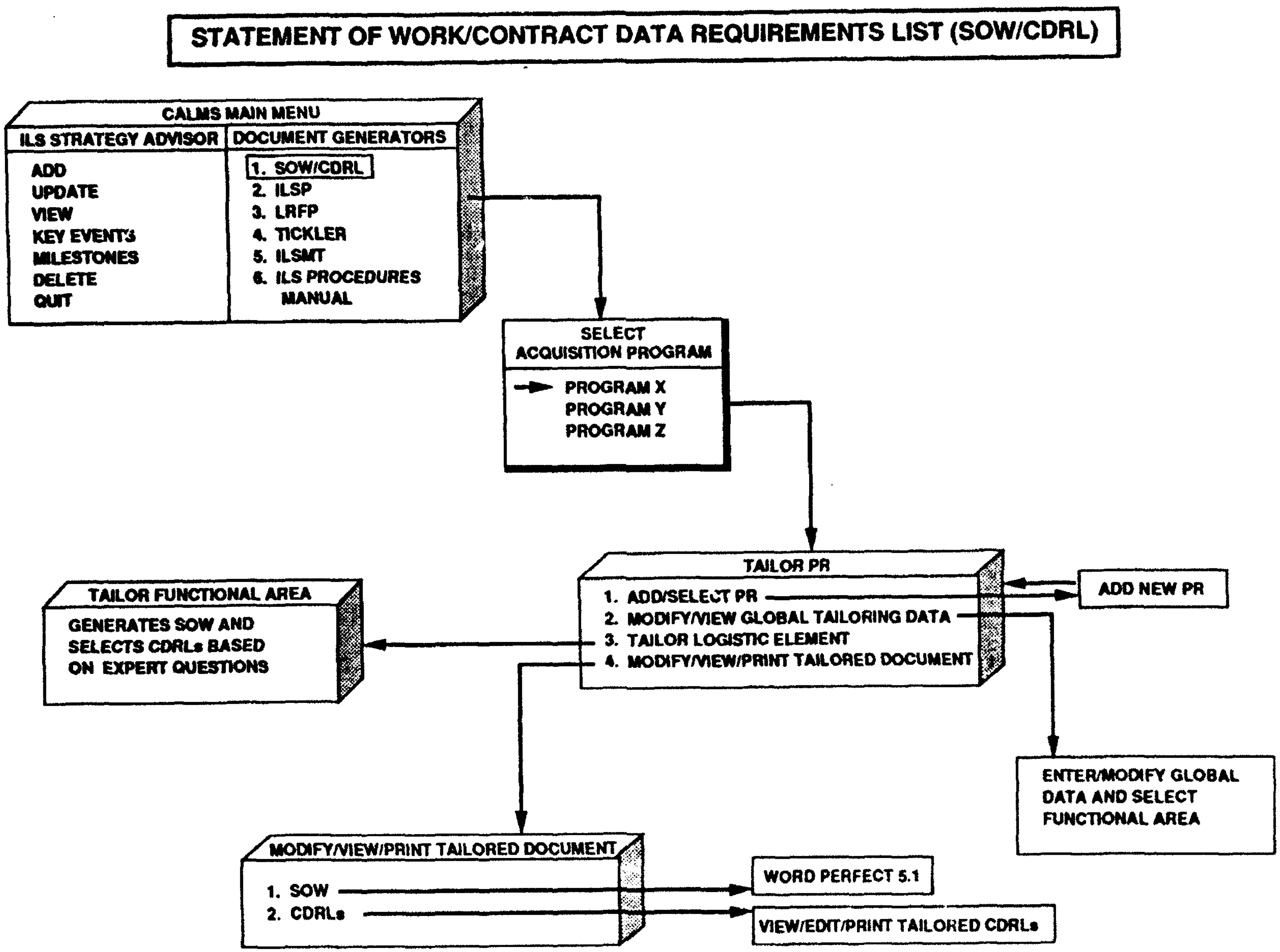

STATEMENT OF WORK/CONTRACT DATA REQUIREMENTS LIST (SOW/CDRL)
CALMS MAIN MENU
ILS STRATEGY ADVISOR
ADD
UPDATE
VIEW
KEY EVENTS
MILESTONES
DELETE
QUIT
DOCUMENT GENERATORS
1. SOW/CDRL
2. ILSP
3. LRFP
4. TICKLER
5. ILSMT
6. ILS PROCEDURES MANUAL
SELECT ACQUISITION PROGRAM
PROGRAM X
PROGRAM Y
PROGRAM Z
TAILOR PR
1. ADD/SELECT PR
2. MODIFY/VIEW GLOBAL TAILORING DATA
3. TAILOR LOGISTIC ELEMENT
4. MODIFY/VIEW/PRINT TAILORED DOCUMENT
ADD NEW PR
TAILOR FUNCTIONAL AREA
GENERATES SOW AND SELECTS CDRLs BASED ON EXPERT QUESTIONS
ENTER/MODIFY GLOBAL DATA AND SELECT FUNCTIONAL AREA
MODIFY/VIEW/PRINT TAILORED DOCUMENT
1. SOW
2. CDRLs
WORD PERFECT 5.1
VIEW/EDIT/PRINT TAILORED CDRLs
8 291 20

FIGURE 11

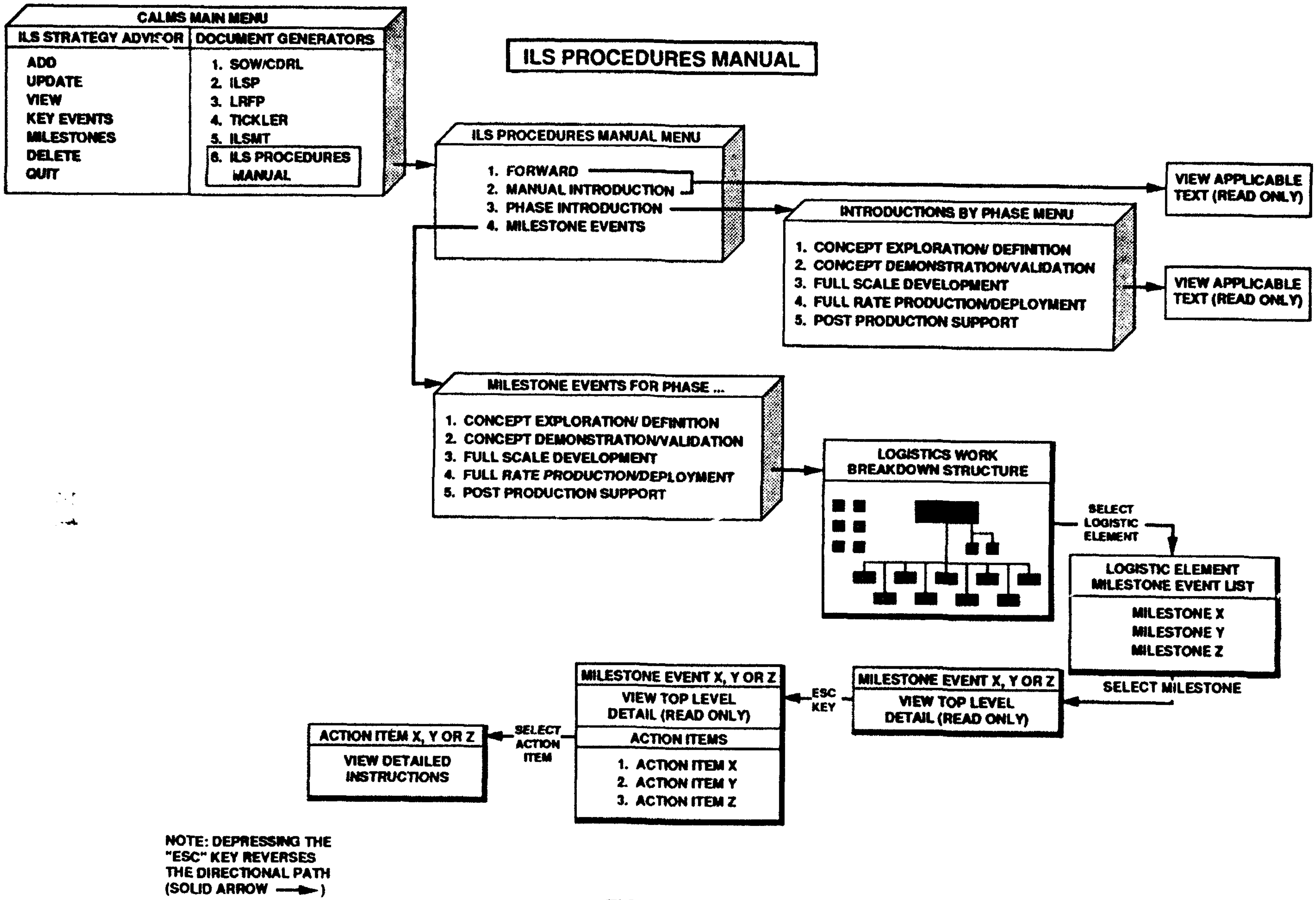


FIGURE 12

9 490 131A

WHY ENGINEERS DON'T UNDERSTAND LOGISTICS

Stephen P. Light
Acquisition and Logistics
Director for Surface Combatants
(SEA 91L)
Naval Sea Systems Command

April, 1991

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor the Department of the Navy.

ABSTRACT

The author describes his observations during twenty-eight years of Naval Ship design, acquisition and logistics support experience that engineers do not understand logistics or even consider logistics as part of their engineering responsibilities. This paper will explore the reasons why. The paper will also provide reasons why the engineer should understand logistics and why it should become a part of the engineer's responsibilities and lexicon. The paper presents the position that an engineer armed with a knowledge of logistics can do the best job in producing a good supportability design. Recommendations are provided to the engineering and logistics communities and ASE to increase the logistics knowledge of engineers. Also, the author advocates the development of more supportability design techniques to be used by the engineer to produce good supportability designs. The increased role of the engineer in applying supportability design techniques will be required in the future if we are to do more with less because of the planned reductions in the acquisition workforce.

FIGURES

INTRODUCTION

The title of this paper may make you angry at first glance, especially if you are an engineer. Frankly, I hope it does make you angry and that you will take an interest in my message that I want to get across to the members of the Association of Scientists and Engineers (ASE). I chose the title to get the attention of the engineers. This is not just an article for the logisticians.

My message has some good news and some bad news. First, the bad news. It is my premise, which is based on twenty-eight years of experience as an engineer and logistician in the area of ship design, acquisition and logistics, that engineers do not understand logistics. The article will explain the reasons why. The good news is that if the engineer did understand logistics and practiced it as one of the engineer's primary duties, then we would be able to do a better job in enhancing our ship, system and equipment supportability characteristics during the design process. The article will provide some recommendations on how we can increase the logistics knowledge of the engineers.

Some disclaimers are appropriate at this point. First, my premise as described by the paper's title is based on my experience. Secondly, there are many engineers that do understand logistics and who do a great job with enhancing supportability during the design process. In fact, this is the main point of my paper: an engineer who understands logistics can do a better job than logisticians when it comes to enhancing the supportability of a design. Now, I have not only offended my engineering co-workers but my logistician friends as well. Although some engineers do a good job with logistics, I believe they are in the minority.

I also have a message for the Logistics Management policy makers. I believe we can improve our approach to accomplishing one of Integrated Logistic Support's (ILS) major objectives which is to enhance the ship, system, and equipment supportability characteristics during the design process. Our existing approach is to train logistics management personnel to work on design teams and with

engineers to ensure that the design process and engineers consider logistics requirements to produce a good design from a supportability standpoint. Why is it done this way? One of the reasons is that the Navy's ILS policy and logistics community consider it part of their job to manage the design interface with ILS because "Design Interface" is one of the key elements of ILS management.

About five years ago, the ship design organization in Naval Sea Systems Command (NAVSEA) had an ILS group that worked on ship design teams to incorporate ILS requirements into the ship design process. This group was disestablished and today we assign a Logistics Management Specialist from the logistics organization to serve as the ILS Manager for a ship design program. The definite trend is toward separating the supportability design function and responsibility away from the ship designer, naval architect and engineers. I believe we need to reverse the existing approach to supportability design and assign the responsibility to the engineer who can do the best job in producing a good supportability design. Some of the reasons that an engineer can do the best supportability design are:

- The engineer best understands the design process and has better control of the design results and products.
- The design process is the result of many competing interests, e.g. cost, weight, size and performance. The engineer can best give supportability an equal billing among competing interests if the engineer understands the importance of logistics and considers it his responsibility during the design process and the life cycle of the design product. Figure 1 provides a few simplified examples of how supportability of a design can easily be improved by an engineer who understands the supportability impact of design decisions.
- ILS personnel are not always considered part of the design team by the engineers.
- ILS techniques often call for too much paper that has to be filled out by the designers. Engineers don't like a lot of paper work which further alienates them from the ILS personnel and reduces their motivation to produce a good supportability design. You can save a ton of paper if the engineer understands what has to be done to provide a supportable design.
- ILS personnel and engineers have problems communicating because each does not understand the others' job.

However, the engineers cannot do the best job now in enhancing the supportability of a design because they do not understand logistics. This paper will explore the reasons why engineers don't understand logistics and offer some recommendations on how engineers can increase their knowledge of logistics and improve the supportability of ship, system and equipment designs.

Before we proceed into the paper, it is necessary to provide some definitions to ensure that the reader understands what we mean by logistics and supportability. Before proceeding with logistics definitions, this paper uses the term "engineer" to include all technical personnel involved with the design of a ship or equipment, including naval architects, designers, technicians and engineers. Figure 2 includes the Navy definition (1) of ILS and related terms used in this paper. For the purposes of the paper, the terms ILS, supportability, and logistics are used interchangeably. The important thing to remember is that the ILS elements as a whole and individually must be considered during the design to produce a supportable design.

What is a good supportability design? This question was addressed in a paper (2) on the meaning of Ship Supportability. The paper stated that ship supportability is a measure of the degree to which the logistic support system can maintain a ship at an acceptable level of operational readiness and material condition. Further,

FIGURE 1

EXAMPLES OF HOW ILS THINKING ENGINEERS/DESIGNERS CAN IMPROVE SUPPORTABILITY

	Non ILS Designer	ILS Thinking Designer
Elevator Machinery	Locates machinery underneath elevator platform at the lowest level in ship, thereby making maintenance access nearly impossible.	Locates machinery at maindeck adjacent to elevator shaft. Right-angle drive used to improve maintenance access.
Storeroom	Storerooms come last and gets what's leftover after all other ship arrangements/spaces have been designated - shotgun pattern.	Main Repair Part storeroom, freeze, chill, and dry storerooms are centralized, and easily accessible. Elevators/hatches are designed for efficient loading of supplies from pier/main deck to storerooms.
Machinery Box	Let's see how much we can cramp into this space - if it fits, it's OK. After all, the machinery box length must be reduced if we are to keep the size of the ship to a minimum length and displacement.	Sizes space not only for fit, but for inplace maintenance access and equipment removal. Accomplishes this without necessarily adding length to the machinery box.

FIGURE 2

INTEGRATED LOGISTICS SUPPORT (ILS) DEFINITIONS

A. **Integrated Logistics Support** - A disciplined, unified, and iterative approach to the management and technical activities necessary to:

1. Integrate support considerations into system and equipment design
2. Develop support requirements that are related consistently to readiness objectives, to design, and to each other.
3. Acquire the required support.
4. Provide the required support during the operational phase at minimum cost

B. **Supportability** - The degree to which system design characteristics and planned resources, including manpower, meet system peacetime readiness and wartime utilization requirements.

C. **Design Interface** - The relationship of logistics-related design parameters, such as Reliability and Maintainability to readiness and support resource requirements. These logistics-related design parameters are expressed in operational terms rather than as inherent values and specifically related to system readiness objectives and support costs of the material system.

D. **ILS Elements** - The elements comprising ILS are:

Maintenance Planning	Manpower and Personnel	Supply Support
Support Equipment	Technical Data	Training and Training Support
Computer Resource Support	Facilities	Design Interface

supportability encompasses the quality of the logistic support system as well as the quality of the design. It implies a matching of the ship design with the logistic support system. In summary, a good supportability design is one where the ship's design and logistic support system (which includes all ILS elements) meets a stated measure of readiness such as an Operational Availability requirement or number. Later in the paper, a design technique, which I call ILS design budgeting, will be described that relates the design and logistics to achieve a specific degree of supportability. This technique can overcome the problem of not being able to quantify whether a design is supportable or not.

The ILS design budgeting procedures will enable the ship or equipment designer to predict to what degree of supportability the design and logistic support system can support. For example, if the design and logistic support system are predicted to be below the readiness requirement, then action can be taken by the designer or logistician to modify the design or the logistic support system to meet the readiness requirement. The ILS design budgeting technique is a powerful tool for the designers and logisticians in the early design phase to quantify what is meant by supportability in specific terms rather than generalities.

ARE ENGINEERS LOGISTICALLY RESPONSIBLE FOR THEIR ASSIGNED EQUIPMENT?

You often get different answers when you ask if an engineer is logistically responsible for his assigned equipment. Usually the answer is no. I have had senior level engineers tell me that they are only responsible for the technical, not the logistics, aspects of their equipment.

NAVSEA uses the terms life cycle engineering and management to describe the responsibilities of the engineers. What do they mean? The NAVSEA Organization Manual defines the terms as: "responsibility, authority and accountability for the direction, control, and decisions or alternative recommendations inherent in the planning, programming, budgeting, development, acquisition, maintenance engineering, logistic support, material management, and disposal of assigned systems and equipment in support of new ship acquisition, Fleet modernization, and Fleet material support".

It would appear if the engineers are to provide life cycle management for assigned equipment and be called Life Cycle Managers (LCMs) in the context of the definition above, then they should certainly have some basic understanding of logistics.

WHY DON'T ENGINEERS UNDERSTAND LOGISTICS?

The following paragraphs will describe the reasons why engineers don't understand logistics. Certainly, the subject of logistics is not that complex for an engineer to learn and understand. After all, engineering is probably one of the most difficult undergraduate programs that can be taken. I have concluded that the reasons are not technical despite the tendency of the logistics community to talk in their own foreign language of acronyms. The reasons are more related to the engineer's background and education which is void of any logistics training and experience. Another important factor is the way the Navy

approaches ILS by training logistics management specialists to be responsible for ILS integration with design rather than training engineers about logistics so they can design in the supportability. This approach has contributed to the engineer taking the attitude that logistics should be left to someone else. The latter part of this paper will explain in more detail the reasons why logistics is not understood by engineers. Also, the point will be made that the Navy can do a better job in supportability design if the engineers are trained to understand logistics and assign them the responsibility to provide a supportable design that meets a specified readiness requirement.

The paper will describe the following reasons why engineers don't understand logistics:

- Existing ILS policy has contributed to the belief that the responsibility for the ILS element, Design Interface, is an exclusive function of the ILS manager, thereby causing the engineer to demonstrate a "Not my job" attitude toward logistics.

- The Engineers' formal education does not include logistics.

- Engineers are not required to complete any logistics training while functioning as an engineer.

- Existing and effective supportability design techniques are limited.

- There are insufficient feedback procedures and no accessible data base to inform engineers of an equipment's supportability performance in the Fleet.

THE WRONG APPROACH TO SUPPORTABILITY DESIGN?

Prior to the establishment of ILS Policy by the Navy in the early sixties, the engineers had a lot more responsibility for logistics and supportability design than they do today. Since there were no ILS Managers around that worried about the ILS element, Design Interface, it was clear that the engineers had the primary responsibility for supportability design and to specify in the equipment and ship specifications, the requirements for logistics. The engineer would often incorporate into the ship specifications, specific ILS requirements, for example, technical manual requirements or special shipboard stowage and test equipment requirements. Also, the spares that would be carried onboard the ship was determined directly by the engineer who specified in the hardware contract the spares' requirement, which were often called "box spares." These spares would be stowed on the ship with the equipment and controlled by the technician instead of todays' concept of the Coordinated Shipboard Allowance List (COSAL) and centralized stowage in the repair part storeroom and management by the ship's supply officer.

Over the years, ILS policy has created its own unique ILS specialists, procedures and expertise that emphasizes a centralized approach to the management of the ILS elements and the integration of ILS considerations into the ship or equipment's design. The ILS requirements were deleted from individual specification sections and consolidated into one central section, for example, section 080, Integrated Logistics Support, of the General Specifications for Ships of the United States Navy. Section 080 centralizes the ILS requirements that was otherwise called out in individual hull related or equipment specification sections. The new ILS management approach also requires trained logisticians to work on design and acquisition programs. These events have contributed to the problems of why engineers don't understand logistics and why they often demonstrate the attitude to "leave it for the logisticians to do."

I believe we could do a better job with supportability design by training the engineers to understand logistics rather than trying to train logisticians about the design process. In the future, it will be even more difficult to place enough logisticians in design and acquisition program offices. My observations are that most programs do not have logisticians onboard early in the design process and have problems manning even major ship design programs with qualified ILS personnel. The shortage of ILS personnel is even worse on smaller acquisition programs where each acquisition category program (ACAT I, II & III) is required (1) to have a qualified ILS manager to assist the program manager at the inception of the program. In view of the projected decreases in the acquisition workforce, the only prudent course is to teach the engineers how to produce a good supportability design and place the responsibility for doing it on the engineers. The logisticians still have the responsibility in the acquisition process to manage the development and delivery of the requisite logistics to support the Fleet introduction of ship and weapons systems.

THE ENGINEERS' FORMAL EDUCATION DOES NOT INCLUDE LOGISTICS

Engineers must have some basic knowledge of logistics if they are to produce a good supportability design. Unfortunately, most engineering and naval architect curriculums in our universities and Maritime Academies do not teach any supportability related courses.

I recently recruited on several Maritime schools where I reviewed the engineering courses required to graduate.

These courses did not include any reliability, maintainability or supportability related courses, either of a theoretical or operational viewpoint. When interviewing the students, I asked them if they had an understanding of logistics and the response was always no! I have reviewed the course curriculum of other colleges that offer engineering programs and found that there are very little courses taught on logistics. My own experience in completing a Bachelor of Science in Mechanical Engineering many years ago is that the engineering schools then did not teach logistics related courses. The same is true of present day engineering schools and curriculums.

Figure 3 is a list of course requirements for a mechanical engineering curriculum that was extracted from a 1991 undergraduate catalog of a major university. The courses, as described by the catalog, emphasize theory and basic mechanical engineering fundamentals. The engineering school's curriculum is designed to provide students with a thorough training in the fundamentals of how to design machines, since this is the stated mission of the mechanical engineering school. Unfortunately, no where in the curriculum are courses on reliability, maintainability, and supportability and how these functions should be applied to the design of machinery.

FIGURE 3
COURSE REQUIREMENTS
FOR MECHANICAL ENGINEERS

NOTE: Curriculum also includes options and elective courses but none could be found on logistics.

FRESHMAN YEAR	JUNIOR YEAR
General Chemistry I, II General Physics Calculus I, II Introductory Engineering Science Statics Freshman English	Electrical Engineering Electrical Engineering Lab Mechanics of Deformable Solids Deformable Solids Lab Intermediate Thermodynamics Transfer Processes Fluid Mechanics Fluids lab Dynamics of Machinery Measurements Lab
SOPHOMORE YEAR	**SENIOR YEAR**
Calculus III Differential Equations Physics Physics Mechanics of Materials Dynamics M E Project Engineering Analysis and Computer Programming Thermodynamics	Material Science Automatic Controls System Design Mechanical Engineering System Design Engineering Experimentation Machine Design Thermal Fluids

The lack of teaching logistics in our engineering schools contributes to the problem of engineers not feeling that logistics is part of their job. Engineers in school are taught basic theory that creates an engineering mindset that concentrates only on the design and performance characteristics of an equipment. As a result, when they come to the job in Naval ship and equipment assignments, they practice what they have been taught which causes them to focus on the design meeting performance requirements and not much consideration is given to logistics.

Our engineering schools, Maritime, and Naval related institutions should offer one or two requisite courses in logistics and how equipment design and ILS are interrelated. The Association of Scientists and Engineers (ASE) should help get the message out to the academic community that more logistics is needed in the engineering curriculum. The ASE's Science and Education Committee could be assigned the task to work with universities, especially local schools, to incorporate supportability education into the engineering curriculum.

ENGINEERS DO NOT RECEIVE ANY LOGISTICS TRAINING WHILE FUNCTIONING AS AN ENGINEER

In addition to a requirement for an engineer to obtain a knowledge of logistics in the engineering undergraduate institutions, there is a need to continue an engineer's logistics education and training while on the job. Unfortunately, engineering activities do not normally encourage their engineers to take logistics related courses as part of their professional development despite the availability of such courses. For example Figure 4 lists a sample of ILS courses that are available to engineers employed by the Naval Sea Systems Command (NAVSEA). These courses are usually free or provided at a nominal cost to Navy activities. Some engineers take these courses on their own initiative. However, there is no formal management objective or direction to require the engineers to take the logistics training.

I believe if we establish and implement logistics training for the engineers, then we would enhance the supportability of Navy ship, system, and equipment designs with a relatively small investment in dollars and personnel. I am not advocating that we train engineers to be supply support specialists or possess detail knowledge of all the ILS elements. This is the proper job and responsibility of the Logisticians. My message is that the engineer should have enough knowledge of logistics to understand:

(1)how they can improve the supportability of the design.

FIGURE 4
SAMPLE LISTING OF AVAILABLE NAVY ILS TRAINING COURSES

Course Title	Duration	Training Activity
An ILS Overview	5 Days	CCPO-CC
Logistics Engineering Applications	5 Days	CCPO-CC
Logistics Engineering Management	4 Days	CCPO-CC
Logistics Engineering Principles	4 Days	CCPO-CC
ILS in the Acquisition Process	4 Days	CCPO-CC
Facilities	2 Days	CCPO-CC
Configuration Management	5 Days	CCPO-CC
Defense Basic Logistics Support Analysis	2 Weeks	ALMC
Maintenance Planning	5 Days	CCPO-CC
Manpower, Personnel & Training	10 Days	CCPO-CC
Packaging, Handling, Storage & Transportation	2 Days	CCPO-CC
Support Equipment	5 Days	CCPO-CC
Supply Support	5 Days	CCPO-CC
Technical Data	5 Days	CCPO-CC
Consolidated CivilianPersonnel Office, Crystal City		CCPO-CC
Army Logistics Management Center		ALMC

(2)how logistics is related to the engineer's life cycle management (LCM) function and responsibility.

(3)how to get help from the logistics community to solve logistics problems that are degrading the operational performance of the engineer's cognizant equipment.

To illustrate the last two items, I recently gave a presentation to a group of engineers on supportability and I got a comment from a young engineer that the Fleet just wasn't trained to properly operate and maintain the equipment for which he was responsible. The engineer did not understand why there was a training problem. He just said that "they" didn't do a proper job in training the ship's force. He had apparently lived with this problem for some time, but just didn't know enough about training to get any information on what was causing the problem. He displayed the attitude that training was someone else's job. This is true, to the extent that the training community operates the training schools for Fleet equipment. However, the Hardware Systems Command develop the training capabilities (Training courses, Equipment) for the equipment and transition it to the training community upon Fleet introduction of the equipment. If the engineer had some basic knowledge of training, he could have communicated his problem to the training community to find out precisely what the problem was and where the training process was breaking down for his equipment. He could have also initiated the action to correct the problem which would have caused him less grief by improving the reliability of his equipment through better trained Fleet personnel.

My recommendations to improve the logistics training and knowledge of engineers on the job are:

- Engineering management must require engineers to include logistics training as an integral part of their professional development and job performance. Logistics training should be included as part of the engineer's Performance Appraisal Review System (PARS) and Performance Management and Recognition System (PMRS).
- Emphasize and require logistics training in the Engineer- In-Training (EIT) Program.
- Advertise the logistics training that is available, for example, Figure 4, to the engineering community.
- Supplement the existing ILS training courses with one that specifically addresses the role that engineers have in enhancing the supportability of a design and the relationship of logistics to the engineer's life cycle management responsibilities.

EXISTING AND EFFECTIVE SUPPORTABILITY DESIGN TECHNIQUES ARE LIMITED

The logistics community needs to assist the engineers by working with them to develop more effective supportability design procedures. Progress has been made in recent years in developing procedures to implement logistic requirements during the design process. For example, design techniques to incorporate maintenance accessibility requirements into the ship's design are now routine (3, 4). Also, unlike twenty years ago, logistics delay time is used by the reliability engineers to compute and evaluate the Operational Availability requirements of ships and equipment.

Nevertheless, I believe much more can be done to enhance the ability of the engineers and logisticians to improve the supportability of a design. I believe the following design for supportability objectives are yet to be optimized:

Quantify RMA, Manning, and logistics requirements.

FIGURE 5
TOTAL ILS DESIGN BUDGETING METHODOLOGY

Total Ship level logistics requirements				
	Manning level (e.g., 350 accommodations) RMA goals (e.g., operational availability)		Maintenance concept(e.g.,maximum onboard maintenance capability) Logistics support concepts (e.g., Readiness Based Sparing)	
HULL (100)	PROPULSION (200)	ELECTRIC PLANT (300)		
		Ship Service Power Generation (311) Generator Sets, Ship Service Diesel (3112) Equipment Level ILS Requirements		
		● MTBF ● MTTR ● AO - Logistic Support Impact	● Maintenance Manhours ● Maintenance Concept/Access	● Manning Skills ● Training ● Support & Test Equipment
Procedures				
	1. Quantify the supportability requirements for the diesel relative to total ship logistic requirements.			
	2. Evaluate the design to determine if it can meet allocated ILS requirements.			
	3. Conduct trade-off analysis to determine optimum balance among diesel design, equipment level ILS requirements and total ship level ILS requirements.			

Relate RMA, Manning and ILS requirements to each other and to the ship or equipment design process.

Involve the engineers more in conducting an evaluation of the evolving design with the ILS requirements.

Communicate the ILS requirements to engineers in a language that they can understand.

The purpose of the highlighted words, Quantify, Relate, Involve, and Communicate is to illustrate where we have been weak in the design process to enhance the supportability of the design. I believe that the technology exists to provide design procedures that would quantify ILS requirements and relate them to the design and each other as well as to communicate them to the engineers.

The following paragraphs will briefly describe a concept, which I will call "ILS Design Budgeting," that could accomplish the above supportability design objectives. This concept is similar to the design budgeting methodology that has been used on some ship design programs to control space and weight design reservations. The objectives of the ILS Design budgeting methodology are to:

- Allocate total Ship level RMA and ILS requirements to specific Ship Work Breakdown Structure (SWBS) levels.
- Evaluate the design capability at the SWBS element level to achieve allocated RMA and ILS values.
- Conduct tradeoffs to determine optimum balance between system design, RMA and ILS.
- Integrate ILS, RMA, and design efforts.

Figure 5 illustrates the concept of the ILS design budgeting concept for a typical ship design program. At the start of the design, the Top Level Requirements (TLR) or other requirement's type of document from the platform sponsor in OPNAV, identifies the ship level ILS requirements. For example, a manning level and Operational Availability requirement may be specified in the TLR. These top level ILS requirements can be allocated to any SWBS level. Figure 5 shows an allocation down to the ship service diesel generator where specific ILS requirements can be identified and assigned to the engineers as a specific design requirement.

With a quantification of the ILS requirements at the equipment level, the engineer will understand what has to be done during the ship's design to meet the total ship level ILS requirements. For example, the manning requirements can be expressed in specific preventive and corrective manhours as can the skill and training requirements. If the allocated maintenance manhours cannot be achieved by the engineer, then the diesel generator design will have to change or the change will have to be accommodated at the ship level by re-evaluating the total ship manning.

The same procedure can be used for Operational Availability which is represented by the following equation:

$$\text{Operational Availability} = \frac{\text{Uptime}}{\text{Uptime} + \text{Maintenance} + \text{Awaiting Help} + \text{Awaiting Parts}}$$

Using a ship allocated Operational Availability requirement, the engineer's design requirement can be expressed in specific design parameters, for example, Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR). Other ILS requirements can be evaluated against the design because training, availability of parts, support equipment, and documentation influence the time it takes to conduct maintenance on the diesel engine.

This same type of procedure is repeated for each ILS element until there's a complete quantification of the ILS requirements at the equipment level. The ILS design budget methodology permits the iterative assessment of the supportability of a design and accurate prediction of the degree of supportability at any phase during the design process.

It is not the intent of this paper to fully develop the ILS design budgeting methodology but only to demonstrate that it could be a very good tool to use to ensure the supportability of our designs. We are using the procedure in the areas of manning and reliability. Also, a concept called Readiness Based Sparing is being piloted on the DDG-52 ship program to identify the supply support (parts) required to achieve a readiness requirement for the ship or equipment. However, the methodology has not been developed to include all ILS elements. It is recommended that more effort be applied by the logistics community to develop effective supportability design techniques that can be implemented by the engineers. It is the only way we are going to be able to do more with less acquisition workforce in the future.

INSUFFICIENT FEEDBACK PROCEDURES ON THE SUPPORTABILITY PERFORMANCE OF EQUIPMENT IN THE FLEET

As an engineer and ILS Manager on a major ship design program, it is important to know the specific supportability problems being experienced by the Fleet. With a good knowledge of the problems, fixes can be made during the design process to improve the supportability of the design and equipment. Unfortunately, many engineers can not easily get access to good data on Fleet performance of their equipment.

Factors contributing to the problem of getting information to the engineer on Fleet supportability performance are:

- Despite existing systems to collect data on an equipment's supportability performance, for example, CASREPs, the data in these systems are difficult to understand.
- Engineers are generally not aware of the existing sources of data on Fleet performance or how to use them.
- Engineers do not have easy access to existing data bases on equipment performance in the Fleet.
- It is extremely difficult to interpret the CASREP/3-M data, especially to pinpoint if the problems are being caused by specific design problems.

There are several existing programs that are designed to correct Logistics problems of specific equipment that are not performing well in the Fleet. The Detection, Action and Response Technique (DART) program manages the corrective action of the Fleet's top bad actors in terms of poor equipment performance, reliability and supportability. The DART program office manages the action necessary to correct the poor performance of the equipment selected for the DART program, normally twenty. Also, the NAVSEA Logistics Center operates the Logistics Readiness Improvement Program (LRIP) that uses CASREP data to determine what parts are contributing to a reduced Operational Availability for Fleet equipment. The LRIP makes corrections to the equipment's allowance list and system stock to improve the effectiveness of the supply support for the equipment.

Nonetheless, the engineers still have problems in using the existing data bases and programs on equipment performance in the Fleet to detect inherent design problems that could be corrected during the design process, for example, a new ship design program. Moreover, the existing data bases do not provide information routinely to the engineers. My recommendation is for the design and logistics communities to use existing Fleet data and programs on equipment performance to routinely provide engineers with easily understood information on equipment operational and logistics performance so corrections can be made by the engineer in future design and procurement actions. Several years ago, the Fleet Material Support Office issued reports on families of equipment that documented an engineering analysis of CASREP data to identify design and logistics factors causing failure. These reports were easily understood and a valuable source for correcting problems during a new design to preclude future problems. Unfortunately, these reports were deleted due to funding problems.

FIGURE 6
SUMMARY OF PAPER'S RECOMMENDATIONS

RECOMMENDATION	RESPONSIBLE ACTIVITY
1. Assign the responsibility to the engineer instead of to the Logistician to produce a supportable design	Engineering and ILS Management
2. Train the Engineers on the procedures to produce a supportable design	Engineering and ILS Management
3. The Engineering, Maritime and Naval related schools should teach logistics related subjects as part of the engineering/Naval Architect curriculum	ASE
4. Improve the Logistics training and knowledge of engineers on the job	Engineering Management
(a) Require engineers to include logistics training as an integral part of their professional development (b) Include logistics training in the engineer's PARS/PMRS (c) Require logistics training in the EIT program. (d) Advertise available logistics training to engineers (e) Develop new training on how to improve the supportability of a design	
5. Develop effective supportability design procedures	ILS and Engineering Management
6. Provide Engineers with feedback procedures and data on supportability performance of Fleet Equipment	ILS and Engineering Management

CONCLUSION

Future supportability design efforts can be improved if the engineers are trained to understand logistics and the job of supportability design is assigned to the engineer. An increased logistics knowledge and role of the engineer in up-front design for supportability and the development of effective supportability design techniques takes on a greater importance with pending reductions in the acquisition workforce. The paper provides recommendations, which are summarized in Figure 6, to increase the logistics knowledge of engineers and to improve the supportability of NAVSEA designs.

REFERENCES

[1] U.S. Department of the Navy, OPNAV Instruction 5000.49A, Subject: Integrated Logistic Support (ILS) in the Acquisition Process (30 January 1987)

[2] Judge, Samuel D., "The Meaning of Ship Supportability," Naval Engineers Journal, Vol. 93 (5 October 1981)

[3] Light, S. P. and Darby, R. M., "Trends in ILS: The Role of ILS in Ship System Design," Naval Engineers Journal, Vol. 85, No. 4 (August 1973)

[4] Guido, Anthony J. and Light, Stephen P., "Ship Design for Maintainability: Experience on FFG-7 Class," Naval Engineers Journal (April 1978)

OPERATIONAL USE OF LOW LEVEL WHITE LIGHTING

David A. Kobus LCDR, MSC, USN
Naval Health Research Center
San Diego, CA. 92186-5122

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ABSTRACT

After a generation of using red ambient light to illuminate submarine compartments at night, the utility of such a lighting system has been questioned. Over the years many watchstanders voiced complaints regarding the requirement to use red light for night time ambient illumination. They indicated problems with headaches, feeling generally fatigued, difficulties in reading, and an inability to discriminate color coded information. These disadvantages led to a change in the operating procedures regarding the use of ambient lighting at night. In an attempt to eliminate the disadvantages associated with red lighting, blue illumination was introduced as a replacement [1]. However, additional disadvantages were found with the blue lighting. The major problem was that blue lighting did not facilitate dark adaptation. This paper is an overview of a series of studies that were conducted over a ten year period to investigate possible alternatives to chromatic ambient illumination. It appears that the use of neutral density filter material to provide low level white lighting is optimal for operator performance while maintaining dark adaptation.

TABLES AND FIGURES

NOTATIONS / DEFINITIONS / ABBREVIATIONS

CIC	Command in Control Center
COMSUBPAC	Commander Submarine Force Pacific Fleet
CNO	Chief of Naval Operations
CRT	Cathode Ray Tube
EEG	Electroencephalography
Ft-C	Foot Candle
Ft-L	Foot Lambert
GSA	Government Service Agreement
LLW	Low Level White Lighting
mL	Millilamberts
ND	Neutral Density
NHRC	Naval Health Research Center
nm	Nanometer
NSMRL	Naval Submarine Medical Research Laboratory

BACKGROUND

Red lighting was instituted during World War II to facilitate dark adaptation. At that time submarines were powered by electric storage batteries and had to surface each night in order to recharge the batteries. While on the surface, men had to stand watch for enemy ships and it was necessary for the watchstanders to be dark adapted before coming on deck. More critical was the necessity for men to be dark adapted at night in the event of a sudden unexpected need to surface. For that reason the crews sought to minimize the time required to dark adapt.

The crews realized that the fastest way to become dark adapted would be to remain in total darkness for several minutes. However, this led to a great number of problems for personnel trying to control the ship. Although the crew wanted to turn off the lights in order to dark adapt, they needed some light in order to carry out their duties. What appeared to be an ideal solution to this problem was suggested by the difference between the human photopic (daylight) and scotopic (nighttime) luminosity curves (see Figure 1). When the intensity of

the ambient illumination decreases, the wavelengths to which the eye is most sensitive changes: at high intensities the eye is most sensitive to 555 nm (yellow-green), whereas at nighttime levels of illumination it is most sensitive to 505 nm (blue). Moreover, Figure 1 indicates that at nighttime levels of ambient illumination the eye becomes relatively insensitive to red light. This led to the proposal that the use of red light would permit men to become dark adapted while still permitting enough illumination to carry out their duties. The rationale was that the red light would stimulate only the long-wavelength portion of the photopic luminosity curve while sparing nearly all of the scotopic curve, thus allowing dark adaptation to proceed, or be maintained, if it had already been achieved. A large number of studies soon showed conclusively that the course of dark adaptation was indeed faster after exposure to red light rather than white [2-6]. There were even claims that red light enhanced dark adaptation compared to the amount of adaptation occurring under no light at all [7], claims which were quickly refuted [8].

Red lighting was adopted by the submarine force and soon became the standard nighttime ambient illumination for submarine shipboard use. The logic for its selection was relatively clear. It was used because it provided enough light to perform various "routine" watchstanding tasks, and it produced the smallest effect on the dark adaptation level (or night vision) of watch standers.

Although red lighting provided ambient illumination to perform watchstanding tasks, it was unpopular. Watchstanders on U.S. submarines began noticing many disadvantages to using red light for nighttime ambient illumination. They complained about headaches, feeling generally fatigued, difficulties in reading, and an inability to discriminate color coded information. As a result, the continued use of red lighting that affected the whole control room was questioned [1]. It was therefore proposed that the same effect could be obtained by having only certain crewmen wear red goggles; only those men who needed to be dark adapted would thus be "inconvenienced," while the rest of the crew could still work in white light. Red lighting and the use of red goggles became the specified mode of nighttime lighting.

Ultimately, the disadvantages of red light led to a change in the operating procedures regarding the use of ambient lighting at night; the continuous use of red illumination throughout the night was abandoned by most ships and the use of red lighting was limited to thirty minutes prior to going to periscope depth. But, for many years, there was no official directive describing the actual procedures that should be followed to obtain an appropriate level of dark adaptation prior to coming to periscope depth. These procedures have been left to the discretion of the commanding officer of each ship. It appears that most submarines operated i a similar fashion, rigging the control room for red 30 minutes before coming to periscope depth and extinguishing all ambient illumination about 10 minutes beforehand. While this change helped to reduce some of the problems with red illumination, it did not eliminate them. More recently, the increased use of color-coded control panels and the imminent use of color-coded CRT displays has resulted in further difficulties. As stated above, initially red lighting was required for watchstanders to be able to see during assigned "routine" tasks. The job description of these operators has changed considerably over the years. For the most part, it has been the rapid pace of technology that has increased the number and complexity of "routine" tasks performed. These tasks may require the operator to attend to fine detail on visual displays, read color-coded information, or be relatively mobile throughout the compartment. This change in task requirements has led to an increase in the frequency of complaints regarding number of headaches, as well as difficulties in reading, log keeping, and an inability to discriminate color-coded information.

The crew of one ship finally took the matter into their own hands and replaced the red filters with blue filters which were readily available through the GSA catalog. They reported that the blue lighting enhanced performance and recommended that it replace the red. After an evaluation by one additional crew, the Submarine Force adopted blue lighting as a replacement for red [9]. Blue illumination was introduced to the Navy as a way to manipulate the environment in order to optimize radar operator performance. The idea was to virtually split the visual spectrum by providing all relevant information on an amber screen at one end of the spectrum (high), while all extraneous information (non-radar related) would be illuminated with blue illumination (low end of the spectrum). The actual technique also required the painting of bulkheads, overheads, etc. in blue. This procedure did provide reported enhancements in performance. Initial testing on the USS Philadelphia SSN 690 did follow all recommended modifications. They reported that after using blue illumination at sea, "significant improvements" in performance were obtained. However, when adopted by the submarine force, only the blue filter was listed in the SHIPALT. In addition, most of the visual displays on submarines are not amber, they are green and white and/or black and white CRTs. However, the change to blue illumination was very popular. Four possible reasons may be suggested for preferring blue illumination. First is the well known psychological effect of improved morale which stems from any change that the participants perceive as being done for their benefit (Hawthorne effect). Second is the fact from physiological optics that long wavelengths (red light) focus farther behind the retina than light of shorter wavelengths and thus require more accommodation to see clearly at the same distance. This can be particularly uncomfortable for hy-

peropes (far-sighted individuals) or for older men who are utilizing most of their accommodative power under close viewing conditions and do not have the reserve for long wavelengths. Third, blue lights, as installed on submarines, provide much more total light than do red. Finally, is the possibility that there is a real enhancement of visual sensitivity inherent in the use of blue lighting. Yet, a report by Molino [10], indicated that even with amber screens no significant improvements were found using blue illumination. Regardless of the reason for the performance advantages reported using blue lighting, it appeared that the operational forces had forgotten the initial reasoning for going to chromatic ambient illumination. Blue lighting is by far the worst chromatic illumination to use if dark adaptation is required. Figure 2 shows the spectral transmission of both the red and blue filter material. The blue filter falls within the sensitivity curve for scotopic vision. Blue lighting seriously degrades the ability of the rods, the night-time photo-receptor, to function. Therefore, blue illumination should not be considered and further discussion of blue ambient illumination will be limited. Although these results are now well documented one still finds various lighting configurations depending upon the type and class of ship, the compartment, and personnel preference. This condition should no longer exist on submarines since the CNO has authorized the use of LLW lighting in operational areas [11].

For almost a decade U.S. Naval ships have been using two types of chromatic (blue/red) ambient illumination. Throughout the Fleet there was very little standardization leading to various modifications in ambient illumination. It is still a significant problem in the surface community. This problem has been reduced considerably in the submarine community, however, the submarine force now needs to standardize the bulb used in each fixture. Each light bulb has its own spectral characteristics which need to be considered. This is a problem currently under investigation.

A series of studies [12-24] have been conducted over the last ten years to evaluate the feasibility of replacing red lighting onboard U.S. submarines with low level white (LLW) lighting. These studies have compared the effects of LLW or red ambient lighting on dark adaptation [18,20], and evaluated performance in operational trainers [21]. In addition, performance in the sonar room [14] and in the control room [18] has been monitored at sea. A review of these studies has recently been published [22]. COMSUBPAC had voiced concern regarding the effect of LLW light on periscope vision during emergency procedures. During an emergency, there may not be time to rig the compartment for black (no light) long enough to allow the observer to completely dark adapt before coming to periscope depth. Therefore, an operational evaluation of periscope use with experienced observers was necessary. Additional studies were conducted exploring operational differences in periscope viewing between the two lighting conditions during simulated emergency conditions, as well as with evaluating various lighting modifications in transitional areas [17].

Kinney [25], has shown that the luminances of different colors cannot be measured accurately with a photometer at low intensities. She provided a nomogram with which to obtain a more accurate brightness match at low levels of ambient lights of different colors. Luria and Kobus [21] used the nomogram to choose the neutral density (ND) of a filter that would match the brightness of blue or white light to that of the red lighting used on submarines. There was, however, a problem when LLW lighting was substituted for red light in compartments and passageways adjoining the control room. LLW lighting, when viewed with peripheral vision, appeared very bright and annoying to the observer. This problem was corrected by adding an additional 0.8 ND (total ND = 2.1) to the passageway filters.

These studies determined that the best alternative to red lighting appeared to be the use of an achromatic lighting system at a level of intensity equal to or lower than that of red illumination. This lighting system, referred to as LLW lighting, appeared to provide significant improvements in performance without disrupting dark adaptation [22]

WHICH LIGHTING SHOULD BE USED OPERATIONALLY?

THE ADVANTAGE OF RED LIGHT

Although it was clear from the outset that dark adaptation is faster after exposure to red light than to white, the magnitude of this advantage was less publicized. A detailed examination of the relevant studies shows that the temporal advantage conferred by the red light is not great and may not be of practical significance in most cases.

THE EFFECT OF INTENSITY

The critical point is that the relative advantage of red over white for subsequent dark adaptation is a function of the intensity of the initial adaptation exposure. A number of studies have shown that as the intensity level of the initial adaptation decreases, the rates of dark adaptation after red or white light become more similar. In other words, the advantage of red adaptation over white is reduced as the intensity of the adapting light decreases. This is true whether what is measured is the ability to detect a spot light or to perceive fine detail, and it holds whether what is being measured is initial dark adaptation

from a light adapted state or the interruption of dark adaptation and subsequent readaptation.

For example, Hecht and Hsia [2] compared the course of dark adaptation after exposure to three levels of brightness of red or white. After adapting to around 350 mL of illumination, it took about 15 minutes longer to dark adapt after exposure to white light than to red; when the initial illumination was around 30 mL, it took about 10 minutes longer with white light; and when the initial illumination was around 3 mL, it took about two minutes longer after the white.

In another study, Hulburt [7] measured the times needed to dark adapt after exposure to equally bright red and white lights at four intensities. He reported that after exposure to 100, ten, one, or 0.1 ft-C, it took longer to adapt after exposure to white by 14, five, one, and one minutes respectively.

In a third study [26], subjects were adapted to various colors and then the time taken to dark adapt was measured. They reported that the time taken to reach twice the final threshold was 10.25 minutes longer after exposure to about 130 mL of white than red, but only two minutes longer after exposure to 5 mL of each color.

Ferguson and McKellar [4] tested scotopic acuity (rather than detection) after adaptation to various colors. They found that after adaptation to 0.5 ft-C white, it took 15 seconds longer to perceive the break in a low contrast Landolt-C than after red adaptation. After exposure to 10 ft-C of white, it took one minute longer to see that target than after exposure to red.

Luria and Schwartz [8] also tested scotopic acuity after exposure to white or red light. They found that after exposure to 22 ft-L, it took an average of 3.9 minutes longer to reach maximum scotopic acuity after stimulation by white light rather than red; after exposure to 3.4 ft-L, it look 3.6 minutes longer after stimulation by white; and after exposure to 0.19 ft-L, it took only 1.5 minutes longer after the white light.

Luria and Kinney [27] studied the effects of brief exposure to light on dark adaptation, measuring the time taken to readapt. When dark adapted subjects were exposed to 20 seconds of light at an intensity of 6ft-L, it took about 2.5 minutes longer to readapt if the light was white rather that red; if the 20-second exposure was at an intensity of .06 ft-L, then the time taken to readapt was only about 1.5 minutes longer with white (See Figure 3).

It is clear that the difference in time taken to dark adapt after exposure to white rather than red light becomes relatively small when the stimulation prior to dark adaptation is of low intensity. Indeed, the differences are so small that Lowry [28] concluded after his study that after exposure to 3 ft-C of illumination, there is no difference in time taken to dark adapt red or white. Sheard [29] agreed with Lowry, stating, "However, I obtained just as rapid dark adaptation and secured as great a degree of night vision through the use of neutral filters which transmitted relatively low amounts of incident light...the use of neutral filters was as satisfactory as that of red goggles..." Hecht and Hsia [2] argued that Lowry's [28] results were due to the pitfalls which occur in trying to equate lights of different colors at low intensities. They believe that Lowry's red and white lights did not stimulate the cones equally, and the results were therefore "irrelevant to the phenomenon they were designed to clarify".

WHY IS RED LIGHT NOT MORE EFFECTIVE?

One would imagine from Figure 1 that a sharp cut-off filter at about 600 nm would indeed allow almost complete dark adaptation while transmitting enough light to the cones to allow reading and the like. Why then is the relative advantage of red lighting surprisingly small?

The reason for the mistaken expectations is that the two highest points on each curve assigned the same value and the rest of the points correspondingly scaled. This is a misleading way to plot the curves, for although each curve shows the relative sensitivity to the various wavelengths for either the rods or the cones, it completely distorts the relation between the sensitivities of the two curves. As Cornsweet [30] has pointed out, "plotting them this way loses important information, and gives the false impression that the cones are actually much more sensitive than the rods in the long wavelength end of the spectrum."

The correct way to compare the two luminosity curves is shown in Figure 4 from which we see that the cones are less sensitive than the rods only below the long wavelength end of the spectrum: in the red wavelength, the rods and cones are actually equally sensitive. Or as it is often put, there is no photochromatic interval in the red end of the spectrum. Figure 4 makes it clear why the relative effectiveness of red light is much less than it is widely thought to be.

RED AND DARK ADAPTATION

The reason for the continued use of red light on submarines remains the desire to facilitate dark adaptation. Although it may not be necessary for submarines to surface every night, emergencies may arise which make it necessary to surface quickly at night. The periscope operators and other members of the crew will want to be dark adapted when the submarine comes to the surface

or to periscope depth. It is for this reason that red light is used at night. Is it still necessary?

First, it must be made clear that red adaptation is not dark adaptation [8]. Complete dark adaptation can be achieved only in the absence of light. Stimulation by light of any color will effect dark adaptation to some extent. Men who have adapted to some level of red light will still require some time to become completely dark adapted when the red light is turned off. The effect of a given level of red light can be equated to some level of white light. For example, Rowland and Sloan [5] have shown that exposure to 2 mL of either red or white light requires a certain amount of time for subsequent dark adaptation, and that 12 mL of red light produces approximately the same degree of adaptation of the rods (the nightime receptors) as 3 mL of white light (See Figure 5). Although this is an advantage for red, it is far from being equivalent to no light at all.

The time required to completely dark adapt has been measured after adaptation to various intensities of red light. Hecht and Hsia [2] found that after adaptation to 3 mL of red light, dark adaptation required a little less than two minutes. Luria and Schwartz [8] found that it took a little over three minutes to be able to resolve and acuity target near threshold after adaptation to 3.4 ft-L of red light. Rowland and Sloan [5] and Hulburt [7] found that adaptation to 3 mL of red light subsequently required about four minutes to dark-adapt. Mitchell [31] reported that after adapting to 6 mL of red, it required 6 minutes to become fully dark adapted.

As discussed above, red adaptation is not dark adaptation, but there is an alternative. The two eyes can be adapted independently; one eye can be light adapted while the other is dark adapted. This is easily accomplished by covering one eye with an opaque eye-patch. Although having one eye light-adapted and one eye dark adapted produces the impression of looking through a veiling light, measurements of target thresholds showed that the illusory light did not interfere with the absolute threshold. It is for this reason that NSMRL recommended the use of an opaque eye-patch over one eye in place of red goggles.

THE PRACTICAL ADVANTAGE OF RED LIGHT

Despite the fact that red adaptation is not equivalent to dark adaptation, it is still better for subsequent dark adaptation than exposure to an equivalent brightness of white light. The next question then is, to what extent will dark adaptation actually be retarded on submarines when the crew are exposed to white light rather than red? The foregoing discussion has made it clear that the magnitude of the degradation will depend on the intensity of the illumination. NAVSEA specifies that normal white light levels shall be about 15 ft-C [32]. When goggles are worn in such an environment, the effective illumination at the eye is then about 1.5 to 2.0 ft-C. When the ship is rigged for red, NAVSEA specifies that the illumination shall not exceed 2.0 ft-C [32]. In fact, our surveys on submarines have shown that the luminance of the various lighted indicators under rig-for-red ranged from .01 to .28 ft-C, and the illumination reflected from the surfaces of the equipment ranged from .01 to .6 ft-L. Light levels in otner compartments are probably quite similar.

If white light were substituted for red light, and these brightness levels were kept the same, then the studies cited above indicated that the additional time required to become fully dark adapted under these conditions would be about 1.5 minutes. Is this added time of practical significance?

In those instances when the crew knows in advance that it will surface, the difference of a minute of two is clearly of no importance. In order to dark adapt, the red light would have to be turned off in advance; if they are operating under dim white light, then the light would have to be turned of a minute or two sooner, a constraint which cannot be of any practical significance.

On those occasions when there is an unscheduled, emergency need to surface or to come to periscope depth, two questions must be answered: What is the total time required to dark adapt, and how long would it take to bring the submarine to periscope depth? Not many studies have measured dark adaptation time from an intensity level of less than 1 ft-C, but Hulburt [7] stated that it is about 4 minutes. Hecht and Hsia's [2] data suggest that it would be even less. Luria and Schwartz [8] found that it took two minutes to reach threshold scotopic acuity after adaptation to 0.2 ft-L. It seems safe to assume that it takes 2-4 minutes to dark adapt from exposure to a low level white. If the submarine must be brought to periscope depth in an emergency, this must also take a certain amount of time. The actual amount of time would depend, of course, on the depth at which the ascent begins. It seems reasonable to assume that on the average it would take one or two minutes. If this is the case, and if the LLW lights were extinguished as soon as the need to ascend was realized, then by the time the submarine came to periscope depth, the crew would be very close to complete dark adaptation.

IS COMPLETE DARK ADAPTATION NECESSARY?

Another question now arises. Is complete dark adaptation always necessary? Probably not. Absolute threshold is around .00001 to .000001 mL for the average young man, although this will vary somewhat with age, the size of target, and other variables. However, the presence of starlight raises it to .001 mL. This is two orders of magnitude greater than absolute threshold. Furthermore, a full moon raises the brightness of the sky an additional order of magnitude (.01 mL). A certain proportion of the time, therefore, the sensitivity of complete dark adaptation is not necessary. Thus, the increment of time required to attain complete dark adaptation resulting from the use of white rather than red light may in many situations be irrelevant.

THE DISADVANTAGES OF RED LIGHT

One further aspect of red light should be considered. Red light has never been very popular. There have always been complaints that it is fatiguing and that it makes it difficult to keep logs and impossible to read color-coded material.

There is little question that the long wavelengths produce some physiological discomfort and degradation. They require more accommodation to focus them on the retina, which could be uncomfortable for older or far-sighted crewmen. Indeed, a study of the eye-movements of men monitoring a sonar display for two under different colors of ambient light gave some evidence of greater physiological fatigue under red light that under blue or white [33]. Other studies have reported that red light has a deleterious effect on such measures as hand tremor and galvanic skin reflex. Kuller showed that color had appreciable effects on EEG, pulse rate, and emotions [34]. He commented that despite some inconsistent results, "there remains an impressive amount of significant evidence showing that illumination and color of architectural space have profound influence on the physiology and behavior of man." Whether or not the ambient light affects such objective variables, there is widespread agreement that it does affect subjective reports of perceived comfort, and that red light is less "restful" than other colors. Several sonar crews have reported that red light is particularly worse under stressful conditions at sea [13].

The widespread unpopularity of red light should not be dismissed out of hand, because it has been shown that there is a relationship between reports of how people feel and their physiological measures. Liebhart has reviewed the evidence that the emotions are aroused when one believes that one has been exposed to an unpleasant stimulus [35]. It is not unlikely that the arousal of such negative emotions degrades performance.

The evidence indicates, first of all, that red adaptation is not a substitute for dark adaptation. Exposure to red light will always result in some degradation of dark adaptation, although when the red light is dim, the loss of sensitivity is small.

Second, although exposure to white light produces a greater degradation of dark adaptation than does exposure to red light, the increment of degradation decreases as the intensity of the lights decreases. In other words, the additional time required for subsequent dark adaptation after exposure to white light rather than red becomes shorter as the intensity of the light decreases. When the light level is as low as that found on submarines which are rigged for red, the time required for complete dark adaptation after the light is extinguished is on the order of two minutes when the light is red and no more than another minute or two if the light is white.

Third, it seems likely that in most cases the submarine will come to periscope depth at a pre-determined time, allowing the crew to take into account the small additional time required to dark adapt. Even when the submarine must come to periscope depth unexpectedly, it seems likely that as appreciable portion of the time required to dark adapt after the lights are extinguished will be taken up by the time required to ascend to periscope depth. Moreover, in many instances, complete dark adaptation may not be required of the periscope operator because of the level of natural light.

Finally, consideration must be given to the disadvantages of red light: it is highly unpopular, it increases fatigue, it has undesirable physiological side-effects, and it makes it difficult to write and to read color-coded material. These disadvantages would be reduced or eliminated if LLW lighting were used.

OPERATIONAL RECOMMENDATIONS

In view of these considerations, one should conclude that the substitution of LLW lighting, equated in brightness to the red, is desirable. The question is, how much time is required for complete dark adaptation when the LLW lighting is turned off? If the white light is set so that the crew is adapted to an intensity level of about 0.5 ft-L, then five minutes is sufficient time for dark adaptation. Th[illegible], if after operating under bright white light, LLW is desired for some portion of the dark adaptation process, then it should be on for about 10 minutes, after which the compartment should be rigged for black for five minutes. If the crew finds it acceptable to run under the LLW lighting condition all night, then, of course, they would never be more than about four minutes from complete dark adaptation.

FUTURE REQUIREMENTS

The initial phase of this research was limited to evaluating the use of LLW lighting for submarines. Theoretically, the results regarding the feasibility of using LLW lighting in operational areas on surface ships should be very similar to the results obtained on submarines. Yet, testing LLW lighting on surface ships requires consideration of several additional variables. The first is that the requirement for dark adaptation on surface ships exists throughout the twilight hours; therefore, the LLW lighting system would be needed for longer durations than what has been recommended for submarines. In fact, most ships continually operate under nighttime illumination conditions in CIC while underway. Thus far, LLW lighting has been used for only short durations as a preadapting period. A proper evaluation needs to be performed to determine the feasibility of using LLW lighting for long periods of time. The second consideration is that the compartment and lighting configurations are much different on surface ships than on submarines. The intensity of light in a compartment is obviously directly related to the number and kinds of lights available. In addition, the tasks that the operators perform and the equipment they use may differ significantly between submarines and surface ships.

REFERENCES

[1] NSMRL ltr NSMRL-01, 3900, Ser 1664, 18 Nov 1970, Subj: Recommendation regarding dual lighting systems for new SSN construction.

[2] Hecht, S., & Hsia, Y. (1945). Dark adaptation following light adaptation to red and white lights. Journal of the Optical Society of America, 35, 261-267.

[3] Berry, W. (1949). Review of wartime studies of dark adaptation, night vision tests, and related topics. Armed Forces-NRC Vision Committee.

[4] Ferguson, H. H., & McKellar, T. P. H. (1944). The influence of chromatic light stimulation on the subsequent rate of perception under conditions of low illumination. British Journal of Psychology, 34, 81-88.

[5] Rowland, W. M., & Sloan, L. L. (1944). The relative merits of red and white light of low intensity for adapting eyes to darkness. Journal of the Optical Society of America, 34, 601-604.

[6] Katz, M. S., Morris, A., & Dimmick, F. L. (1954). Effect of various durations of red adaptation on the course of subsequent dark adaptation. NSMRL Report 246.

[7] Hulburt, E. O. (1951). Time of dark adaptation after stimulation by various brightnesses and colors. Journal of the Optical Society of America, 41, 402-404.

[8] Luria, S. M., & Schwartz, I. (1960). Effect of red vs. white adaptation and target illumination on the temporal course of scotopic acuity. Journal of the Optical Society of America, 50, 1075-1080.

[9] COMSUBLANT ltr 4720, FF4-12:N421, Ser 2885, 24 Jun 1982, Subj:COMSUBLANT A & I Item - install broadband blue lighting in sonar control room.

[10] Molino, F. W. (1982). Submarine use of broadband blue lighting in the sonar control room. NUSC Report 23251-3.

[11] CNO ltr, Ser 224F/6U384607 of 29 Dec 1986.

[12] Kobus, D. A., & Luria, S. M. (1988). At sea evaluation of low level white lighting on surface ships. NHRC Report 88-2.

[13] Kobus, D. A., & Luria, S. M. (1986). Operational evaluation of low level white lighting. NHRC Report 86-24.

[14] Kobus, D. A., & Luria, S. M. (1985). Acceptability of low level white lighting in the sonar room at sea. NSMRL Report 1055.

[15] Kobus, D. A., & Neri, D. F. (1985). Sonar performance under various color of lighting. The Submarine Review, October, 52-56.

[16] Kobus, D. A., & Neri, D. F. (1984). Performance and preference on a sonar detection task under various colors of ambient illumination. NSMRL Report 1023.

[17] Luria, S. M., & Kobus, D. A. (1985). Immediate visibility after red and white adaptation. NSMRL Report 1045.

[18] Luria, S. M., & Kobus, D. A. (1985). Acceptability of low level white lighting in the control room at sea. NSMRL Report 1050.

[19] Luria, S. M., & Kobus, D. A. (1985). Red light, white light. Proceedings of U.S. Naval Institute. August, 123-126.

[20] Luria, S. M., & Kobus, D. A. (1984). The relative effectiveness of red and white light for subsequent dark-adaptation. NSMRL Report 1036.

[21] Luria, S. M., & Kobus, D. A. (1983). Preferences for blue and white light in sonar compartments. NSMRL Report 1013.

[22] Luria, S. M., Kobus, D. A., & Neri, D. F. (1986). Performance and preference under chromatic ambient illumination. Proceedings of the 10th Symposium of Psychology in DOD, 16-18 April, U. S. Air Force Academy, Col. Springs, 1-5.

[23] Neri, D. F., Luria, S. M., & Kobus, D. A. (1984). Visibility of various target background color combinations under different chromatic ambient illuminations. NSMRL Report 1027.

[24] Neri, D. F., Luria, S. M., & Kobus, D. A. (1986). The detection of various color combinations under different chromatic ambient illuminations. Aviation, Space, and Environmental Medicine, June, 555-560.

[25] Kinney, J. A. S., Luria, S. M., Neri, D. F., Kindness, S. W., & Schlichting, C. L. (1981). Surveys of lighting and working conditions in submarine sonar shacks. NSMRL Report 955.

[26] Peskin, J. C., & Bjornstad, J. M. (1948). The effect of different wavelengths of light on visual sensitivity. Memo. Rep., U.S.A.F. Air Material Comm., Wright-Patterson AFB, Dayton, OH.

[27] Luria, S. M., & Kinney, J. A. S. (1961). Interruption of dark adaptation. NSMRL Report 347.

[28] Lowry, E. M. (1943). Effect of hue on dark adaptation. Journal of the Optical Society of America, 33, 619-620.

[29] Sheard, C. (1944). Dark adaptation: Some physical, physiological, clinical, and aeromedical considerations. Journal of the Optical Society of America, 34, 464-508.

[30] Cornsweet, T. N. (1970). Visual perception. New York: Academic Press.

[31] Mitchell, R. T., Morris, A., & Dimmick, F. L. (1950). The relation of dark adaptation to duration of prior red adaptation. NMRL Report 166.

[32] Naval Sea Systems Command: Lighting on Naval ships, 0964-000-2000, Jul 1974.

[33] Neri, D. F., & Kinney, J. A. S. (1982). Contrast sensitivity measured in low levels of red, white, and blue ambient illumination. NSMRL Report 989.

[34] Kuller, R. (1981). Non-visual effects of light and color. Document D15:81, NTIS, Springfield VA, U. S. Dept. of Commerce.

[35] Liebhart, E. H. (1980). Perceived autonomic changes as determinants of emotional behavior. In D. Gorlitz (Ed.), Perspectives on attribution research and theory: The Bielefeld Symposium. Cambridge, MA: Ballinger.

[36] Benson, W., Ghirardi, L., Kobus, D. A., Luria, S. M., Lambert, R. E., Massey, R., & Plath, D. W. (1988) Report of the Ohio-class ship control station illumination committee: Analysis and solution of illumination-related problems on the ship control station of Ohio-class submarines. NPRDC TN 88-4.

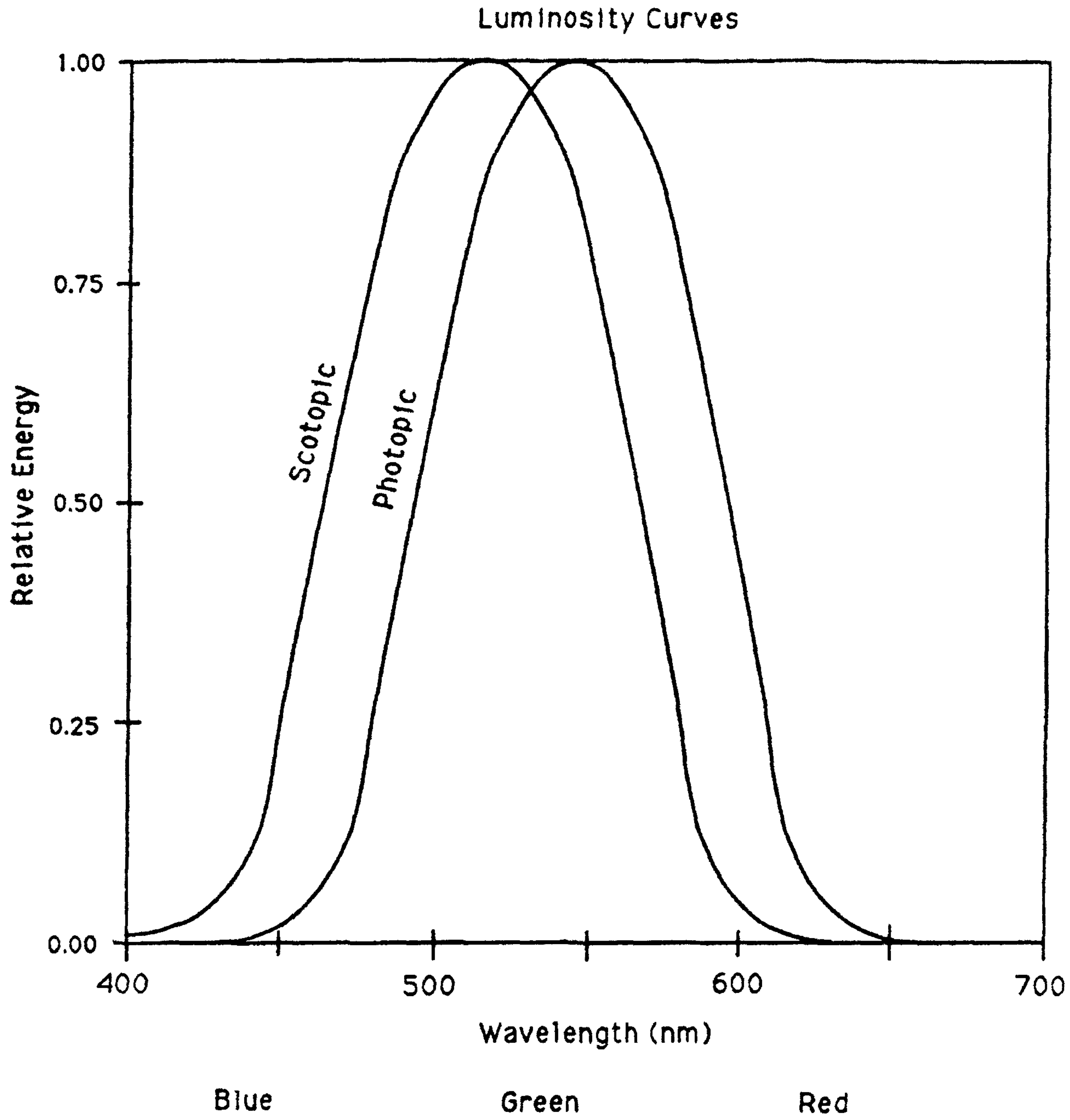


FIGURE 1. PHOTOPIC AND SCOTOPIC LUMINOSITY CURVES

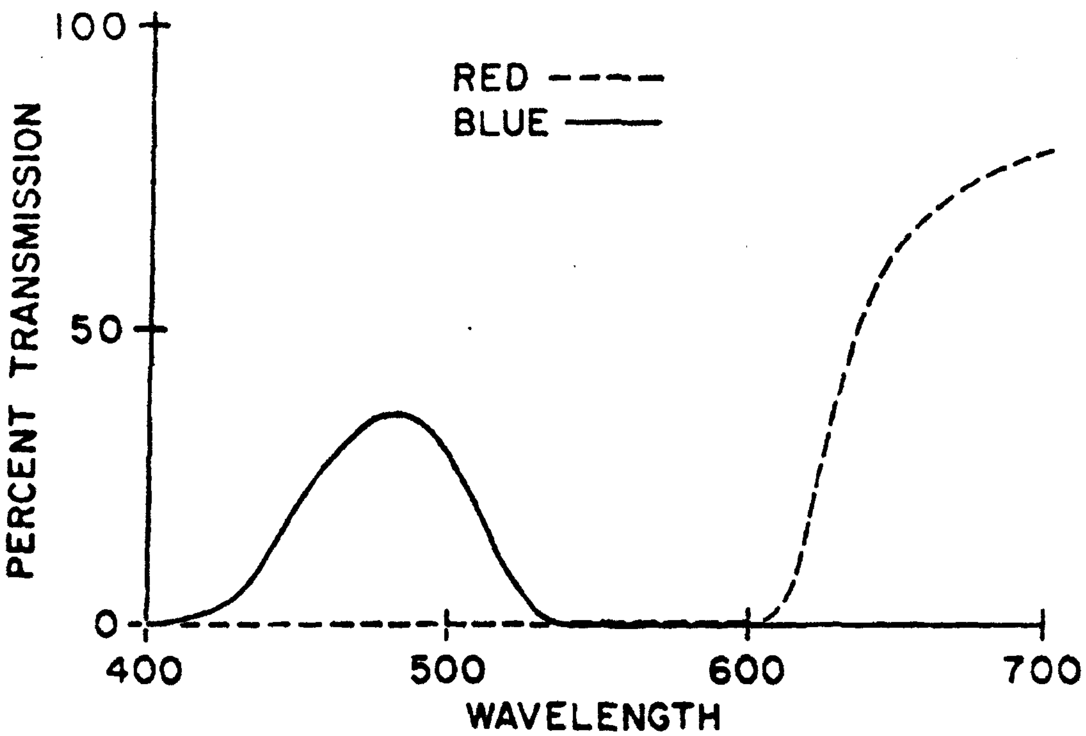


FIGURE 2. TRANSMISSION OF BLUE AND RED FILTER MATERIAL

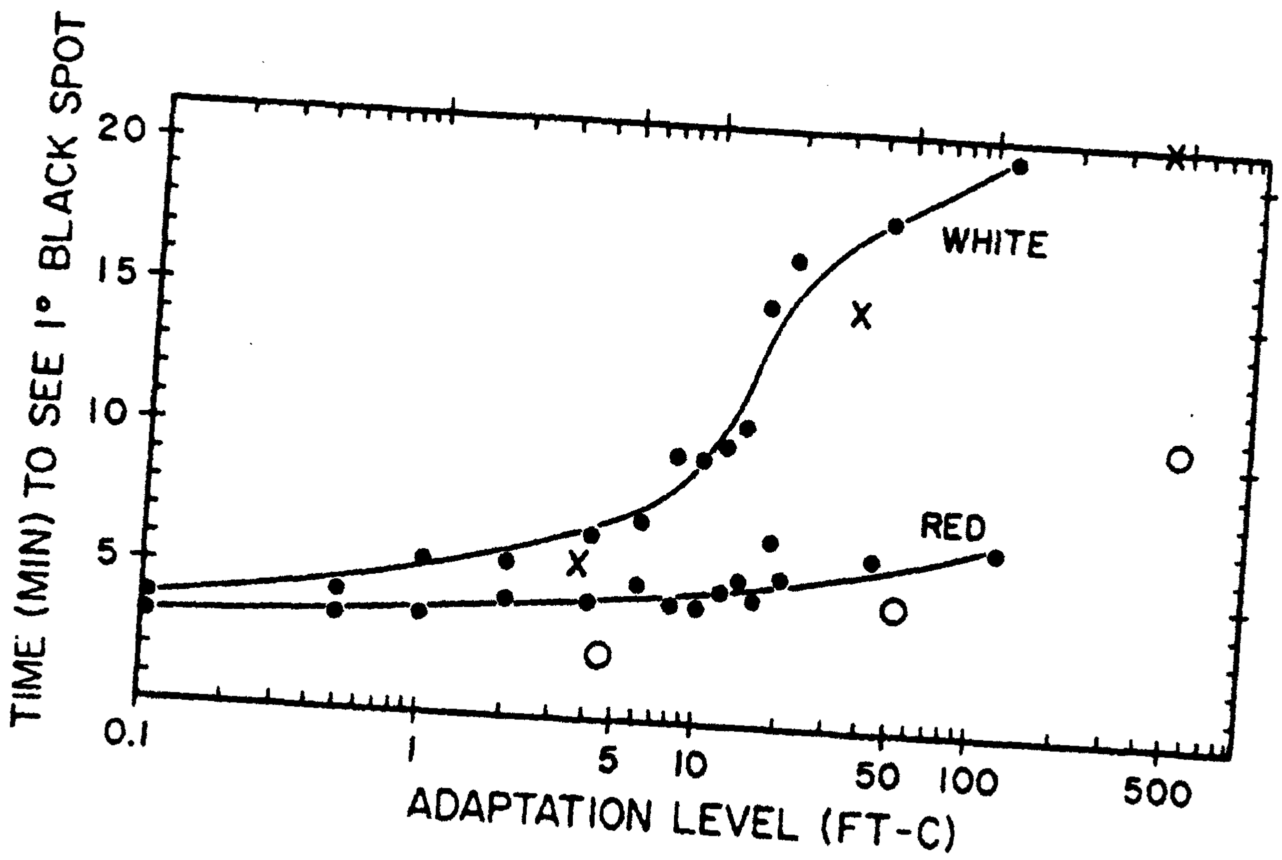


FIGURE 3. ADAPTATION TIME BY PRE-EXPOSURE LIGHT LEVEL

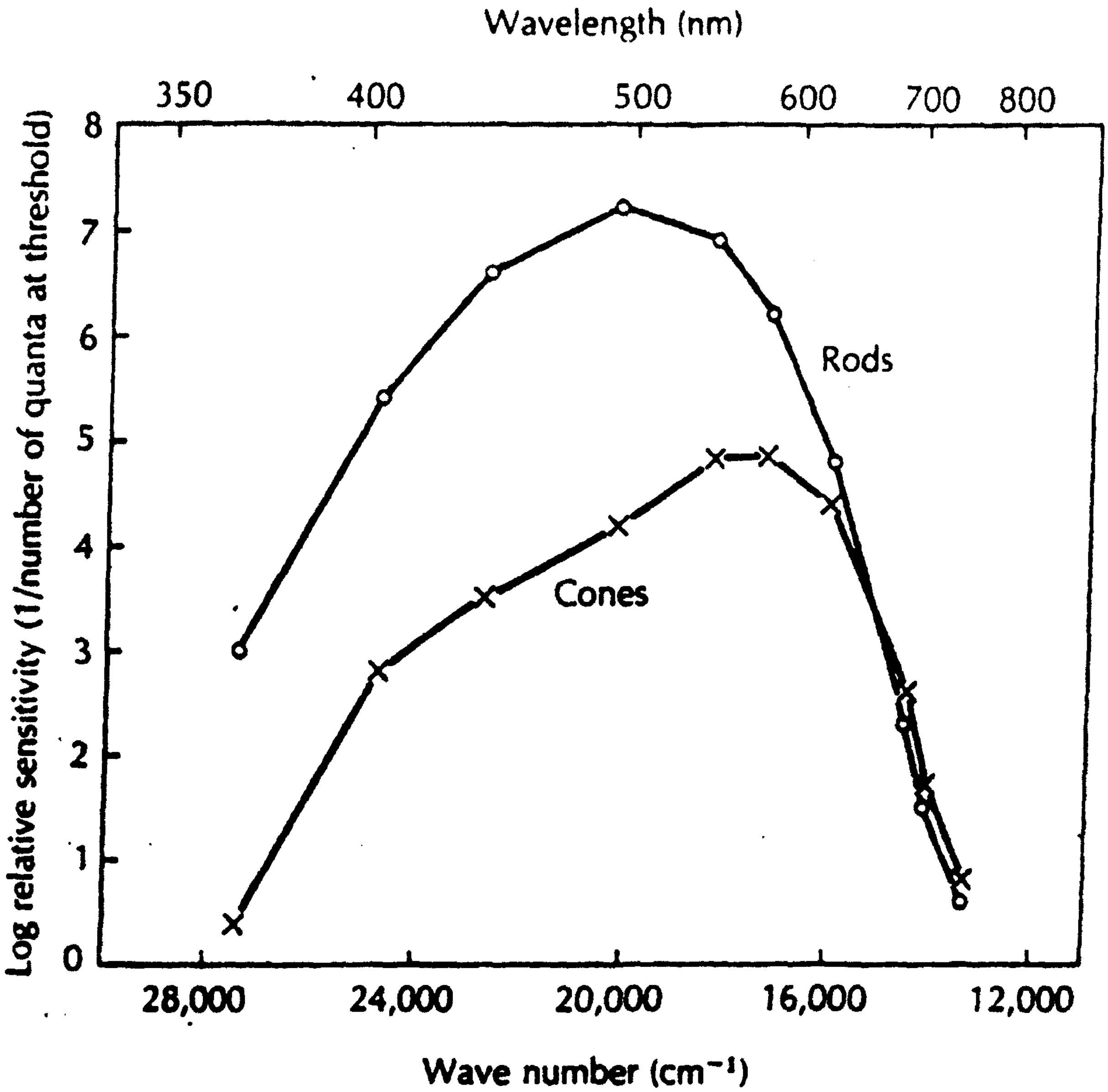


FIGURE 4. APPROPRIATE PHOTOPIC AND SCOTOPIC LUMINOSITY CURVES

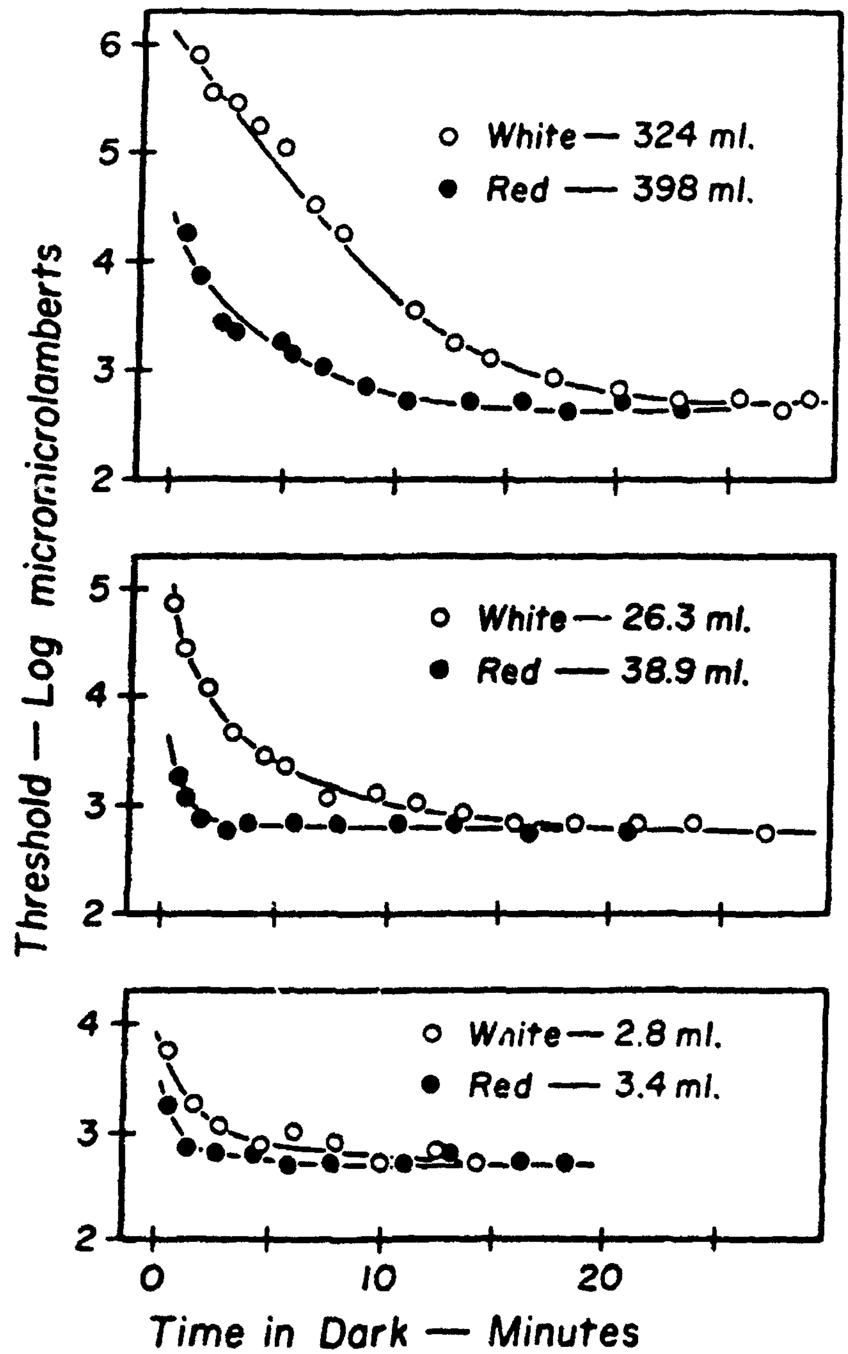


FIGURE 5. ADAPTATION TIME BY PRE-EXPOSURE LIGHT LEVEL

FFG 61 PROTOTYPE DIGITAL TECHNICAL LIBRARY

CAPT. Charles A. Vinroot, USN
Program Manager
Gas Turbine Surface Combatant Program
(PMS314)
Naval Sea Systems Command

Jeffery G. Orner
Fleet Logistic Support Branch Head
Gas Turbine Surface Combatant Program
(PMS314L1)
Naval Sea Systems Command

April 1991

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense nor the Department of the Navy.

ABSTRACT

USS INGRAHAM (FFG 61) is the prototype ship for NAVSEA's Advanced Technical Information System (ATIS). ATIS is a digital technical library, which holds on optical disks the ship's 2,000 technical manuals and 73,000 drawing sheets. It contains a detailed ship's configuration index (derived from SCLSIS) to lead the user to the proper drawing or manual, and it replaces the ship's aperture cards and the second (library) copy of the technical manuals. The system was installed on the ship on 1 August 1990, and is currently being used successfully on board. It was also installed at the FFG 7 Class Planning Yard and the FFG 7 Class Planning SUPSHIP in October 1990. The ATIS system was developed by PMS314, in cooperation with NAVSEA 04TD, and the SPAWAR Technical Data Center. ATIS, and the data standards established and tested through ATIS development, will be the technical library portion of micro-SNAP and SNAP III. It also forms an important part of NAVSEA's plans to utilize EDMICS data, and to streamline our management of technical data through programs such as the Advanced Industrial Management (AIM) program.

This paper describes the goals and technical concepts behind the development of ATIS. Problems encountered, solutions developed, and lessons learned are detailed. Special attention was paid to the application of the Computer Aided Acquisition and Logistic Support (CALS) standards, problems caused by conflicts and ambiguities in those standards, and recommendations for future application and tailoring of the standards. Original program goals are compared with actual operational experiences. Plans for future expansion are outlined, including applications of this technology in the availability planning and execution process (a process which involves enormous quantities of data). A comparison is developed among the various methods of optical imaging and their costs and benefits.

FIGURES

ABBREVIATIONS/ACRONYMS

ASCII	American Standard Code (Version Two)
ATIS	Advanced Technical Information System
ALS	Computer-Aided Acquisition and Logistic Support
CD-ROM	Compact Disk Read Only Memory
DSRA	Docking Selected Restricted Availability
EDMICS	Engineering Data Management Information and Control System
ILO	Integrated Logistic Overhaul
OMMS	Organizational Maintenance Management System
NIRS/NIF	Navy Implementation of Raster Scanning/ Navy Image File Format
NPPS	Naval Printing and Publication Service
RFP	Request for Proposals
SCLSIS	Ships Configuration and Logistic Support Information System
SGML	Standard Generalized Markup Language
SNAP	Shipboard Non-Tactical Automated Data Processing
SSR	Ships Selected Records

SUPSHIP Supervisor of Shipbuilding, Conversion and Repair
TMPODS Technical Manual Print on Demand System
WORM Write Once Read Many

INTRODUCTION

USS INGRAHAM (FFG 61), the final ship of the FFG 7 Class, was delivered to the Fleet with the Navy's first digital technical library - the Advanced Technical Information System (ATIS). This CALS project was undertaken by PMS314, with the participation of NAVSEA 04TD (the Technical Data Division) and the SPAWAR Technical Data Center. This paper is an evaluation of the FFG 61 digital technical library project, its applications both shipboard and at industrial activities, and recommendations for the future.

This first Fleet implementation had several objectives:

- Reduce shipboard weight and space devoted to technical data.
- Provide the ship with interactive technical data search and retrieval capabilities, making it easier to locate the proper document or drawing, and to use the data.
- Scan existing paper technical manuals in order to provide printed-on-demand copies to Fleet and other users. This will enable the Navy to reduce paper stocks of technical manuals, reduce warehouse costs, and stop the deterioration of camera ready originals of older technical manuals.
- Begin the task of converting technical data to a digital form in order to automate the ship maintenance and modernization planning processes. Prepare for the introduction and implementation of the Navy Engineering Data Management Information and Control System (EDMICS).
- Provide a real world prototype in order to test out emerging CALS standards and technology.
- Devise an affordable, cost effective means of converting existing paper technical data into a usable digital form.

The FFG 61 ATIS project has successfully met the above objectives. The remainder of this paper discusses the original FFG 7 Class constraints which led us to undertake this effort; how the above objectives were defined and met; the contents of the digital technical library; compliance with the CALS standards; the hardware and software employed; weight saved; and plans for the future.

FFG 7 CLASS HISTORY

In September 1970, the Chief of Naval Operations, Admiral E. R. Zumwalt, Jr., initiated feasibility studies for a new class of ocean escort ships. Originally designated as Patrol Frigates (PFs), these ships are now known as Guided Missile Frigates (FFGs). USS OLIVER HAZARD PERRY (FFG7) is the first ship of the Class, which has now grown to a total of 55 ships. This number includes four ships for the Royal Australian Navy. Additionally, the Royal Australian Navy is building two FFG 7 Class ships in Australia. Spain and the Republic of China (Taiwan) are also building FFG 7 Class ships.

In 1970, two important considerations converged. One was the realization that the World War II destroyers were rapidly approaching the ends of their useful lives. The other was the recognition of the increasing importance of the sea lines of communication to the prosperity of the United States in peacetime and her survival in wartime. These two factors combined to generate a need for a large number of new escorts which could be built quickly. In keeping with the economic and political realities of the times, they would have to be capable of being constructed and operated cheaply. These needs dictated a concept that would incorporate simplicity and low risk; use of complex, integrated hardware and software systems was to be avoided.

Such ships are the antithesis of the general-purpose destroyers, or cruisers, which are designed to cope with all predictable threats and which, by the nature of modern warfare, are destined to be complex, large, expensive and somewhat technically risky. Designing and building these ships would require more resources and more time than would simpler vessels, and economic considerations would limit their numbers. Such sophisticated ships were seen as essential components of carrier battle groups, for instance, but their use to escort convoys would be overkill. The need to reconcile these conflicting considerations led to the evolution of the "High-Low" Concept.

FFG 7 Class ships were the Low portion of the concept. DD 963 Class ships, along with CGN 38 Class ships were the High portion. In today's terms, CG 47s and DDG 51 Class ships are the High mix ships and because of the concept of Flexible Transition, there are no Low mix ships. This current concept calls for the construction of only Battle Force capable, or High mix ships and the transition of the lesser capable ships as their age makes them non-threat capable to the role of the Low mix ships. This concept is workable so long as economic considerations allow the construction of sufficient numbers of the Battle Force capable ships.

As a Low mix ship, the FFG7 Class ship was constrained by three major limitations:

- Accommodations - 185
- Follow Ship Average Cost - $45.7M (unescalated FY73$)
- Full Load Displacement - 3400 Tons

It is this last constraint which leads one to conserve weight wherever possible and which led us to the concept under discussion. Even this limit was a relaxation of a previous displacement limit of 3000 Tons which was provisionally imposed in May 1971.

Without going further into the detailed history of the Class which is available in Reference [1], a brief discussion of the displacement growth is necessary to appreciate the importance of the current efforts at weight reduction.

Despite the best efforts of the CNO, the ship grew from many "necessities" to an average displacement for the ships authorized in FY75-78 of 3790 tons. The naval architectural limit was 3900 tons which could not be exceeded without longitudinal strengthening of the hull. This growth led to development of a Ship Alteration for this hull modification which currently limits the maximum displacement to 4100 tons for the ships so equipped. The weight/stability status is still watched continuously with 100 percent compensation required, i.e. a pound removed for a pound added.

Future Warfighting Improvement Planning has specific weight reductions mandated and the ATIS system described herein serves both the added convenience of the digital reference system and a portion of this weight savings.

BACKGROUND ON THE FFG 61 ATIS PROJECT

In 1988, as the final ship of the FFG 7 Class was under construction, CAPT Vinroot, NAVSEA PMS314, was briefed on the EDMICS program and was given a demonstration of an EDMICS prototype. After that demonstration, PMS314 researched available technologies and the status of CALS. It was decided to make use of these technologies, and, among other things, to deliver USS INGRAHAM (FFG 61) with the Fleet's first digital technical library.

Our premise was that the use of electronic technical manuals and drawings would reduce the weight and bulk of paper on board the ship. This would also provide the data in an easy to use form, providing technical data to ships which are easier to manage and update. Both on board ships and on shore, the electronic data base reduces the time required to search and retrieve information and to update the data. This should also result in keeping these data current. Through the Integrated Logistic Overhaul (ILO) process, it has been clearly demonstrated that technical manuals on board ships are very often not maintained. The laborious process of inserting change pages into the thousands of manuals carried by a ship, combined with the crush of more pressing duties, has brought us to a point where many of the technical manuals in use do not have the most current updates inserted. This could result in costly, and even dangerous, mistakes. Providing the data in an electronic data base allows the process of maintaining manuals to be largely eliminated on board ships. Updated technical manuals and drawings will be provided on a periodic basis, much like the semiannual Force revisions used to distribute Planned Maintenance System (PMS) data currently. Changes will already be incorporated on a new disk, or changes could be sent to the ship on a floppy disk, which could be copied into the digital technical manual, incorporating the change pages in seconds.

Our approach to implementation of CALS is to use demonstration projects to prove concepts. We chose available, affordable technology which we can grow with, and we ensure that there is a return on the investment before full scale implementation. In order to ensure that the program remains affordable, it is critical to use and comply with CALS standards and to ensure full compatibility with the EDMICS program. This was accomplished. Compliance with CALS standards will enable ATIS to benefit from the data and software developed by other Navy CALS programs. Compliance with EDMICS was important because the scope of EDMICS makes the program and its constraints a standard. Through the EDMICS contract, the Navy will establish a series of repositories for an estimated 190 million drawings and 500,000 publications. EDMICS is an engineering drawing and publications management system, which will have a profound effect upon Navy management of data. ATIS compatibility with EDMICS ensures that compatible data will continue to be available for future ATIS applications.

This project was built upon two other PMS314 demonstration projects. The first of these involved the most recent Drydocking Selected Restricted Availability (DSRA) for USS O'BANNON (DD 987). For the modernization portion of that availability, the work specifications, drawing schedules, drawings, standard items, technical manual references, and other related data were placed on an optical disk. Work stations were made available to the DD 963 Class Planning Yard, the Planning SUPSHIP, and the executing Naval Shipyard. Because this was a limited

demonstration project, a very limited number of work stations were provided. Despite the limited number of work stations, the project did demonstrate the ability to respond rapidly to changes, the data were more easily accessible, and important lessons were learned as to the indexing of the data provided on the system. Users found the data to be easy to access, but requested more indexing and cross referencing of the data. Based on these lessons learned, the FFG 61 ATIS project began with the building of a complete configuration and logistic index to enable the user to quickly find the reference required. We built this index by adding complete identification of each functional configuration item installed on board, and cross referencing technical manual and drawing references. This then served as the index to ATIS, and as FFG 61's Ship Configuration and Logistic Support Information System (SCLSIS) data which is also resident on the Shipboard Non-Tactical Automated Data Processing System (SNAP II) and in the Weapon Systems File. This integration of supply and engineering data is essential to effective management of the data, and this same technique is being applied across the board.

The other demonstration project which preceded ATIS was the installation of a technical drawing data assess/stowage system on board USS STARK (FFG 31). During the restoration of USS STARK, all of the drawings involved in the restoration were scanned and placed on two optical disks. The ship was provided with a work station. These disks contained 38,000 drawing sheets. A relational data base linked the drawings to configuration records. The technology was proven to be cost effective. Changes were made to later versions of the software to reflect user preferences. Improved shipboard access to drawings was accomplished. The drawings could be accessed by functional configuration references or by drawing number. Based on this demonstration project, we decided to expand the scope for FFG 61 to include other types of data used frequently on board ships and in the maintenance and modernization processes, such as technical manuals and Ship Selected Records (SSR).

Technology exists today to drastically improve technical data management and storage capabilities. This type of project was not feasible on earlier ship construction projects, because existing technology, at the time, did not allow for the massive data storage required and, until recently, the cost was prohibitive. Optical disk technology now allows for vastly increased storage and retrieval capacity. Compact Disk - Read Only Memory (CD-ROM) allows for storage and unlimited retrieval of data. Write Once Read Many (WORM) optical disks allow the user to write to the disk and allow unlimited retrieval (data cannot, however, be erased). One 5 1/4 inch WORM disk holds 800 megabytes of data. This is many times the storage capacity of the average personal computer. One 14 inch WORM holds 6.8 gigabytes of data.

Raster scanning of text documents, paper drawings and aperture cards creates a dot matrix image of the data. Unlike a word processing system or a Computer-Aided Design (CAD) system, a raster image is simply a photograph-like image of the data scanned. New programs will acquire drawings in an intelligent form (ASCII/SGML documents) which can be manipulated in word processing systems. To convert existing paper documents, however, to this form through use of optical character recognition scanning is prohibitively expensive. Once the data have been converted to an intelligent form, extensive line by line quality assurance is required to ensure that the new intelligent data base reads exactly the same as the original document. The consequences of converting, say, a "6" to an "8," in the process of converting a paper document to a data base, could be serious. With the quality assurance cost added in, Navy programs have paid $5 to $10 per page to convert paper into data bases. The option of converting paper to an intelligent (ASCII/SGML) data base was rejected as too costly for an existing program which has already procured the bulk of its data on paper. In order for the ATIS effort to succeed, it was essential that the life cycle cost of providing and maintaining the data be no greater than the cost of today's processes.

Raster technology, which converts a page of text and graphics to a digital binary format, stores an exact image of the page. Raster images are high quality, easily retrievable, viewable and printable. This conversion is easy and fast. Very little quality assurance of the scanned images is required. The cost of such conversion ranges from $0.40 to $1 per page. For a program such as the FFG 7 Program, with vast quantities of paper, this is the only affordable option. The variation in raster scanning costs depends on the amount of indexing of the documents one chooses. This indexing allows the user of the raster document to move automatically to indexed section titles, page numbers, figures, etc. We opted to index header information defining each document, as well as table of contents, all section numbers and titles, and the lists of illustrations and figures. The indexing can be tailored, with pages selected for their usefulness in searching the document. This allows the user to easily move through the document, jumping to pages needed.

Optical imaging software, now widely commercially available, allows for ease of viewing of raster images of both drawings and text documents. This software, which is inexpensive, allows for zooming, panning, rotating and printing of drawings, and for paging, linking text and printing of documents. These raster playback systems are quite affordable and allow the user to retrieve on a monitor or send to a printer, an accurate copy of the document or drawing. This software runs on micro-computer hardware, thus saving space.

Raster technology was selected for the ATIS program for the above reasons. Selection of raster technology also has the advantage that future raster scanned documents will become available as a by-product of the technical manual automated reprint process, which is utilizing raster images. Playback software for raster data is simple and inexpensive. Raster does have disadvantages. It requires massive data storage capabilities. The availability and affordability of optical disk technology, however, mitigates this disadvantage. The data search and retrieval capabilities of a fully intelligent (ASCII/SGML) based data system are faster and allow for increased capabilities such as key word searches through the entire text, unlike raster. As stated above, the initial cost of converting paper to an intelligent form, combined with the quality assurance costs and the expensive play back software required for an intelligent data base, made this option too expensive for general use. Although an effective prototype of a fully intelligent data base could be fielded, the added capability of such a system is outweighed by the greatly increased original and life cycle costs. Such systems, however, hold promise for new programs which can obtain original data in the appropriate form. Indexed raster data will continue to be the preferred option for data which exists on paper today.

Sever major categories of data were selected for inclusion in the program. ATIS is the FFG 61's technical library, replacing the ship's paper technical library. FFG 61 carries 2,000 technical manuals. Most of these are equipment level operations and maintenance manuals and system level technical manuals. The remainder of the technical manuals are publications of a general nature. The only technical manuals excluded from the scanning process were those with color pages, those containing any classified data, and those manuals existing only in very poor print quality. In addition, the SSR were scanned. SSR consist of Selected Record Drawings which illustrate important features, systems, and arrangements applicable to an individual ship; and, Ship's Selected Record data, which describes arrangements, systems, equipment, and procedures essential to the operation and safety of the ship. Finally, all of the ships NAVSEA and vendor drawings (every drawing listed in the Ship's Drawing Index) were included. 73,000 aperture cards were scanned. During 1991, PMS documentation and Engineering Operational Sequencing System documentation will also be available to be played on ATIS. These additional categories of data are becoming available at no additional cost to the program because of the use of standards now being applied by other Navy programs.

An FFG normally carries two copies of each technical manual. One is in the work center and one in the technical library. The 2,000 copies of technical manuals carried in the technical library are removed with the installation of ATIS. The work center copies remain. In addition, an FFG carries aperture cards representing approximately 80,000 drawing sheets, along with aperture card readers. All aperture cards and associated equipment are also removed. This results in a net weight savings of approximately 4,000 to 5,000 pounds. This will vary, of course depending on the extent of the documentation scanned and removed, and depending on the number of ATIS work stations installed.

This section has reviewed how the ATIS program got started, and technological and cost constraints. The objectives outlined in section 1 were defined in joint sessions with NAVSEA 04TD. The objectives were defined in this manner in order to derive maximum benefits from the project, to ensure that this was a NAVSEA Command project rather than an independent effort, and to ensure that the program would be easily exportable and sustainable.

CALS STANDARDS

Compliance with Navy standards, especially those of the CALS program, proved to be the most difficult technical challenge of the ATIS effort. This was also the most significant accomplishment of the program. To establish a computer storage and retrieval system is not difficult. What is difficult is establishing and maintaining compatibility with other Navy and industry programs and standards. Only through diligent application of those standards can the task of automating our processes and procedures be accomplished in a cost effective manner.

The drawings were scanned in a tiled raster format conforming with the digital drawing standards of the EDMICS program. Tiling is a procedure whereby the drawing images are broken up into sections (512 X 512 pixels), to improve efficiency of data manipulation. The drawings images employ the .C4 header record. The major standard employed was MIL-R-28002 [2]. The images were compressed in accordance with CCITT Group 4, which is an international industry standard, and is, in fact, the same standard employed in the process of FAXing documents.

The standards for scanning technical manuals were less definitive, and this program was used to proof draft standards. The technical manual operating system was developed as a joint NAVSEA, SPAWAR, and NPPS initiative. A draft Navy Military Standard, MIL-M-29532(EC), has been produced for publication [3]. This standard defines a process being referred to as "intelligent raster." The result is a practical compromise between the indexing, accessing and other high performance features associated with intelligent ASCII/SGML text files, and the relatively simple raster based picture image. The "intelligent raster" supports a moderate degree of indexing and accessing capability at a

cost 1/10 that of converting paper documents for use with comparable ASCII based linked text (hypertext) systems. The data utilizes the Navy Implementation of Raster Scanning/Navy Image File Format (NIRS/NIF), which is a Navy implementation of the CALS standards for delivery of technical manuals in a raster format [4]. NIRS/NIF defines a set of header information describing the contents of the technical manual data file and establishes an untiled data storage format for 8 1/2 by 11 inch pages. EDMICS invokes a tiled format for 8 1/2 by 11 inch (A-sized) images. While we opted for the untiled images, ATIS utilizes a compression decompression board which recognizes and can utilize either the tiled or the untiled images.

To the extent that CALS standards are defined and tested, they were strictly applied. Where conflicts existed, such as the tiled versus untiled images, we made every attempt to allow for either format. An open, non-proprietary architecture was maintained in order to maintain maximum flexibility and Navy control over the system. Perhaps the ultimate test of the standards came about because the actual scanning was completed by several different commercial and government entities. The data all proved to be compatible and can be played on ATIS without any reprocessing or reformatting.

A significant challenge, was the fact that Navy paper technical manuals comply with no one format. Page numbers are sometimes out of order or missing and the formats and layout of the manuals vary depending on when the manual was produced and on the quality assurance. While this does not make a great difference to the user of the paper manual, it makes a difference to software written to accommodate technical manuals in specific formats. All of this created problems which had to be addressed as they arose in the scanning process.

The FFG 61 ATIS system was designed as a client-server architecture. The system utilizes an SQL-compliant data base management system and operates in a Windows 3.0 graphical user interface. The index was extracted from SCLSIS, and is fully compliant with SCLSIS standards [5]. A new version of shipboard ATIS is now being tested which incorporates a seamless interface with the Micro-OMMS software. Micro-OMMS will be a part of Micro-SNAP, and utilizes the screens and user interfaces in use in the Fleet today. This interface will allow Fleet sailors, in the process of reporting maintenance actions or configuration changes or ordering parts, to utilize ATIS on the same screen they are working on and to call up the actual technical manual or other technical data needed. This is important to the transition to SNAP III, the shipboard non-tactical ADP system of the future.

FFG 61 ATIS SOFTWARE AND HARDWARE

This section will describe the makeup of ATIS. ATIS, as delivered to FFG 61, differs in only one way from ATIS, as delivered to the Planning Yard and Planning SUPSHIP. The shore activities have edit capabilities which have been turned off in the shipboard version. This reflects the function of those activities.

Figure (1) depicts the ATIS software and lays out its various modules. We will describe each of those modules beginning with 1.0, the master index. The master index is a copy of the SCLSIS index with specific information added to tell the user which data are located on which disk. Technical data are related to the configuration item supported. All configuration items are related to each other by a process of hierarchically structuring and uniquely defining each specific application of each functional configuration item. The index provides a top down breakdown of all of the ship's systems and equipment, and describes 100 percent of the ship's configuration with no redundancy. In other words, the user can find a particular technical manual or drawing by starting at the system level and walking down to the specific equipment the technical manual or drawing supports, or the user can simply enter a technical manual or drawing number. Other SCLSIS data elements, including supply and engineering oriented data elements, can be used to enter the system and find technical data references. While the master index now exists independently from the ship's SNAP II data base, it can be updated from the same data sources. Future ATIS installations will allow the master index to be updated with the same monthly Automated Shore Interface (ASI) tape the ship uses to update the SNAP II data base.

The technical manual module (2.1), contains the software for retrieval and manipulation of the 2000 raster scanned technical manuals. The intelligent raster indexing capability allows the user to jump to a specified page, to page backward or forward, to go directly to figures or to call up the table of contents and jump directly to listed sections. Key word searches are limited to indexed elements (i.e. section titles). This indexing approach provides a series of page-level indexing tags which enable the user to move within the technical manual. A special word file translates word files for indexing the technical manual into ASCII indexes: table of contents, list of illustrations, list of figures, etc. The user can call up a figure or text reference as a second page in a separate window alongside the first. A 19 inch monitor was provided to enable the user to view two nearly full sized pages at once. Concurrent display of multiple pages is limited only by the amount of main memory. Multiple pages are stackable in the Windows environment, and can

FFG-61 (USS INGRAHAM)
ADVANCED TECHNICAL INFORMATION SYSTEM (ATIS)
BASELINE 1.0

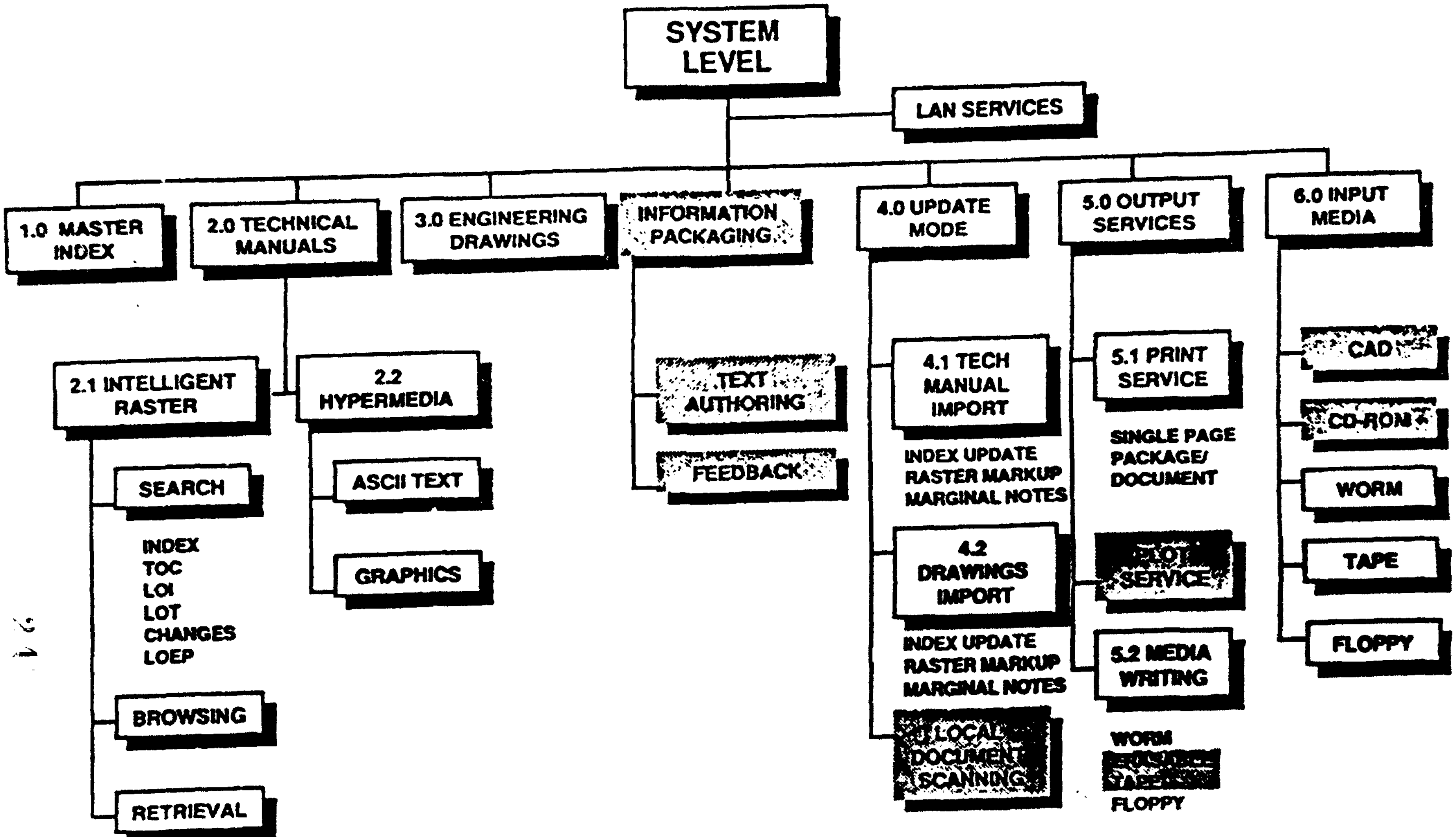


FIGURE 1

be saved as icons, and retrieved almost instantly. The user can zoom in on any desired portion of the image. Shipboard and Planning Yard users have found that the zoom feature makes figures and images previously too small to be useful, easy to read and use. This makes the technical data more useful than in the paper or aperture card format and has proven to be among the most beneficial and popular of the system's features.

Also under the technical manual module (2.2), is the hypermedia demonstration. Although intelligent raster is the format of choice, a representative sample of 5,000 pages (Fin Stabilizer technical manual, and three NSTM chapters) was converted into ASCII through Optical Character Recognition (OCR), and then integrated with linked text capability to demonstrate full text word searches. Unlike a conventional paper based document which must be read right-to-left and top-to-bottom in a sequential manner, a linked text document is arranged relationally. The user is able to move freely from one topic to another according to the users needs. All references, indices, graphics and other document constraints are represented as objects which can be examined separately, or as a group depending upon the user's preference. Presentation aspects such as font size, search mechanisms, and navigational capabilities are available. This linked text demonstration was performed to more fully explore the comparative costs and benefits of fully intelligent versus raster data. Our conclusion, as discussed above, is that intelligent documents are prohibitively expensive to create from paper. For programs procuring new documents, however, we recommend that standards and delivery requirements be invoked for intelligent character-based text data and raster-based illustrations in new contracts. If this approach is adopted, intelligent raster data and fully intelligent data systems can coexist on the same hardware, with intelligent (ASCII/SGML) data gradually replacing raster scanned technical manuals as new systems and ships replace older systems and ships. This, of course, will take place over a period of decades. We view this as the only approach which will provide the benefits of a digital product today, while remaining affordable in today's fiscal environment.

The engineering drawing module (3.0) provides access to USS INGRAHAM's 73,000 drawing sheets. Pan and zoom features are provided, with the same functionality as described above for technical manuals. The ship's drawings have been indexed to the drawing number level. Accessing the drawing through either the master index function or by entering a drawing number, will retrieve all sheets of that drawing. Partial drawing numbers can be entered for retrieval of a list of all drawings containing that number. This same partial search feature applies to all search fields, both numeric and text (technical manual number, Hierarchical Structure Code, Equipment Functional Description, etc.). The imaging software offers several useful features. Initially, the system displays the first sheet of the drawing in an overview mode. The user may then elect to view the entire sheet, any portion of the sheet, or the user may select subsequent sheets either in sequence or may go directly to any sheet. The user can pan the drawing image or zoom in to create any specific image. the invert feature changes white pixels to black and vice versa. The rotation option allows total image rotation of 90, 180, or 270 degrees. Any image on the screen can be printed on a standard printer, or the entire drawing can be plotted, if a plotter is available.

The update module (4.0) allows for the import of new drawings, technical manuals and changes into the system so that collated documents can be displayed, and provides for the update of the indexes. The user can import either a new WORM disk sent from a shore facility or can import data from a floppy disk (i.e. a technical manual change package) onto a WORM. The process currently in place will assign the Class Planning Yard the responsibility to send out drawing changes. Technical manual changes will be coordinated by the Naval Sea Data Support Activity. The distribution of electronic technical manuals directly to ships and users at shore activities has several benefits. The users will receive completely up to date technical data, and this technical data will be packaged to meet the needs of the activity. Technical data can even be sorted by work center for convenience of the shipboard users. Update of the data will be automatic, resulting in technical libraries which remain fully up to date with very minimal effort required by the user. The users of the information will be able to obtain from their library and print exactly the information needed for a specific task. Portions of documents can be printed and even cut and pasted with other documents.

The output module (5.0) controls the printing functions. A laser printer is provided to print "on demand" either entire documents or portions of them. Shore facilities will generally have a plotter for drawings. Data can also be written to a WORM disk or a floppy disk. The input module (6.0) provides for input of data from a variety of standard digital sources.

Figure (2) displays the make up of an ATIS work station. A 386 based personal computer is recommended. In addition, a WORM drive is needed, as well as a compression-decompression board (available for purchase in the EDMICS contract), and a mouse. The software is an integration of Navy owned software and inexpensive commercial off-the-shelf software. System integration was performed by a contractor under the direction of NAVSEA. In 1991, the software/system integration functions will be turned over to the Navy Computer and Telecommunication Station (NCTS) in Jacksonville, Florida. Hardware was obtained competitively through NCTS. This sometimes made the system integration function

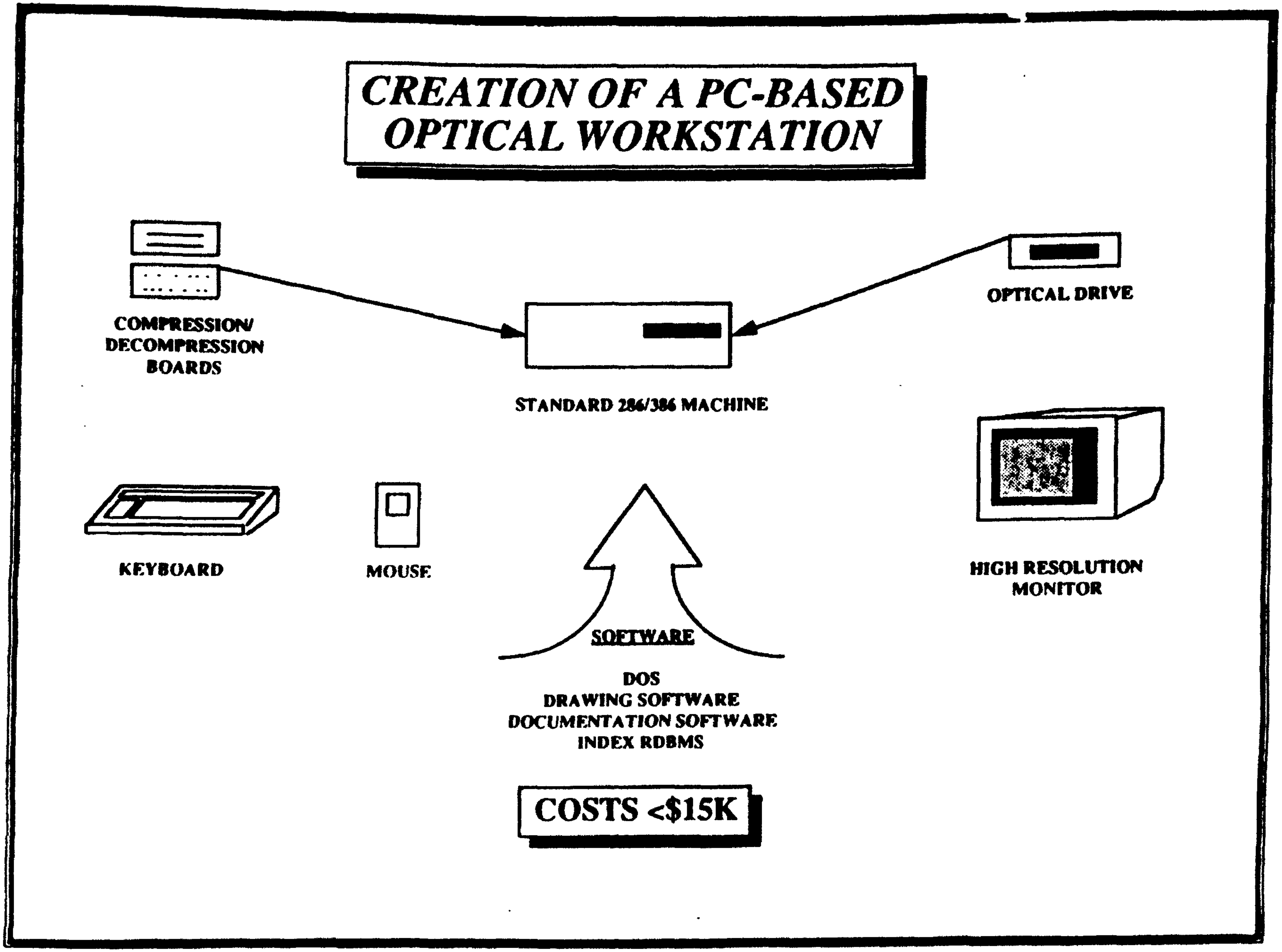

CREATION OF A PC-BASED
OPTICAL WORKSTATION
COMPRESSION/
DECOMPRESSION
BOARDS
STANDARD 286/386 MACHINE
OPTICAL DRIVE
KEYBOARD
MOUSE
HIGH RESOLUTION
MONITOR
SOFTWARE
DOS
DRAWING SOFTWARE
DOCUMENTATION SOFTWARE
INDEX RDBMS
COSTS <$15K

FIGURE 2

more difficult than sole source procurements, but once completed, hardware independence was proven. Because of the lack of an industry standard for WORM drives, a WORM drive was selected on the basis of physical compatibility with EDMICS. The physical layout of the network installed on FFG 61 is depicted in figure (3). The Planning Yard's network is depicted in Figure (4).

SUMMARY AND FUTURE PLANS

The USS INGRAHAM (FFG 61) ATIS system is the first Fleet implementation of a digital technical library. It provides on-line access to SSR, technical manuals, NAVSEA drawings, and vendor drawings through the use of intelligent raster images. Both the initia' procurement and design, and the life cycle cost of scanning and providing the digital data have been proven to be cost effective. A relational data base provides access to the data through use of a complete configuration index, built to SCLSIS standards and tailored to provide ease of access to users from the operational, engineering, and supply communities. The software can be run on a stand alone work station, on a network in an office environment, or as part of a shipboard non-tactical ADP network.

The FFG 61 ATIS project reflects two noteworthy accomplishments:

- digital data integration based on formal government and industry standards, and an open, non-proprietary architecture.
- the development of practical and affordable procedures to manage, in a digital environment, the enormous inventory of existing paper technical manuals and aperture card drawings. Figure (5) depicts today's procedures and the digital processes, which will replace them.

Future plans for application of this technology include the possibility of centralized Government Furnished Information (GFI) management as well as digital drawing management and production. The FFG 7 Class Planning Yard (Long Beach Naval Shipyard) has already used ATIS for the production of selected Ship Alteration Installation Drawings (SIDs). Other future plans include elimination of aperture cards and at least one copy of technical manuals from ships and production of complete request for proposal packages in digital form. PMS314 is cooperating with the Navy's Advanced Industrial Management (AIM) program, which seeks to achieve efficiencies in ship maintenance and modernization through application and further development of this technology. The prospect of a paperless availability is a real possibility.

Major objectives for the future of PMS314's CALS program include building a central repository of digital technical data, integrating this repository with other data systems (e.g. the Fleet Modernization Program Management Information System, EDMICS, In Service Engineering Agent's data bases, and logistic data systems) using SCLSIS to integrate the reference data. Application software will be selected or created to create and distribute digital bid specification packages (reference data included), to distribute data to users, create work packages, etc. Contractors proposals could even be received in a standard digital form and preliminary evaluations and comparisons made using expert systems.

FFG 7 Class work packages consist of alterations, which are performed on a class basis, and maintenance work items driven by the Class Maintenance Plan (CMP). The large size of the class and the repetitive nature of the alterations and maintenance work afford the possibility of significant cost savings, improved quality, and increased efficiency. These benefits can be achieved through streamlining, automating, and integrating availability planning, execution, and administrative processes and systems. Simple system changes can be achieved to reduce contractor claims based on late, conflicting or inaccurate GFI, and by ensuring that an update to one data source automatically drives updates to the same data in other forms and repositories.

Near term plans include installation of ATIS work stations at Ship's Intermediate Maintenance Activities (SIMAs) to provide easy assess to up to date technical information at those facilities. The FFG 7 Class Planning SUPSHIP, (SUPSHIP, Jacksonville, FL) has already tested the production of digital specifications, and the recent installation of ATIS should allow for production of complete digital RFP packages.

We will close with a review of the project's original objectives, and a brief discussion of how they were met.

1. Reduce shipboard weight and space devoted to technical data. This objective was achieved with the removal of the 2,000 technical manuals, and 73,000 aperture cards discussed above.

2. Provide the ship with interactive technical data search and retrieval capabilities, making it easier to locate the proper document or drawing, and to use the data. Reports from users on FFG 61 and at shore facilities have been uniformly positive. The data are easier to access and more usable due to features such as the zoom capability, and easier to update.

3. Scan existing paper technical manuals in order to provide printed-on-demand copies to Fleet and other users. This will enable the Navy to reduce paper stocks of techni-

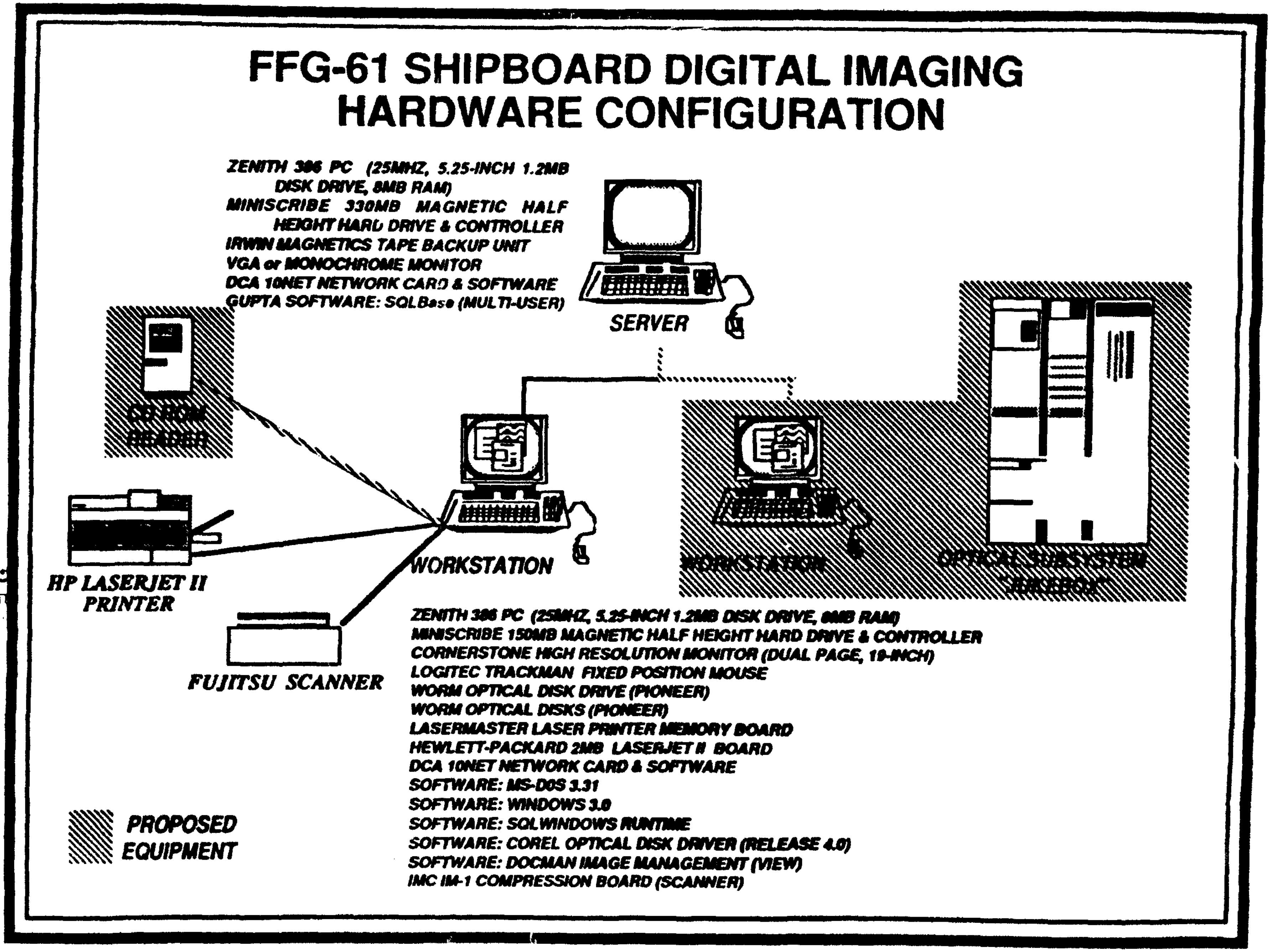
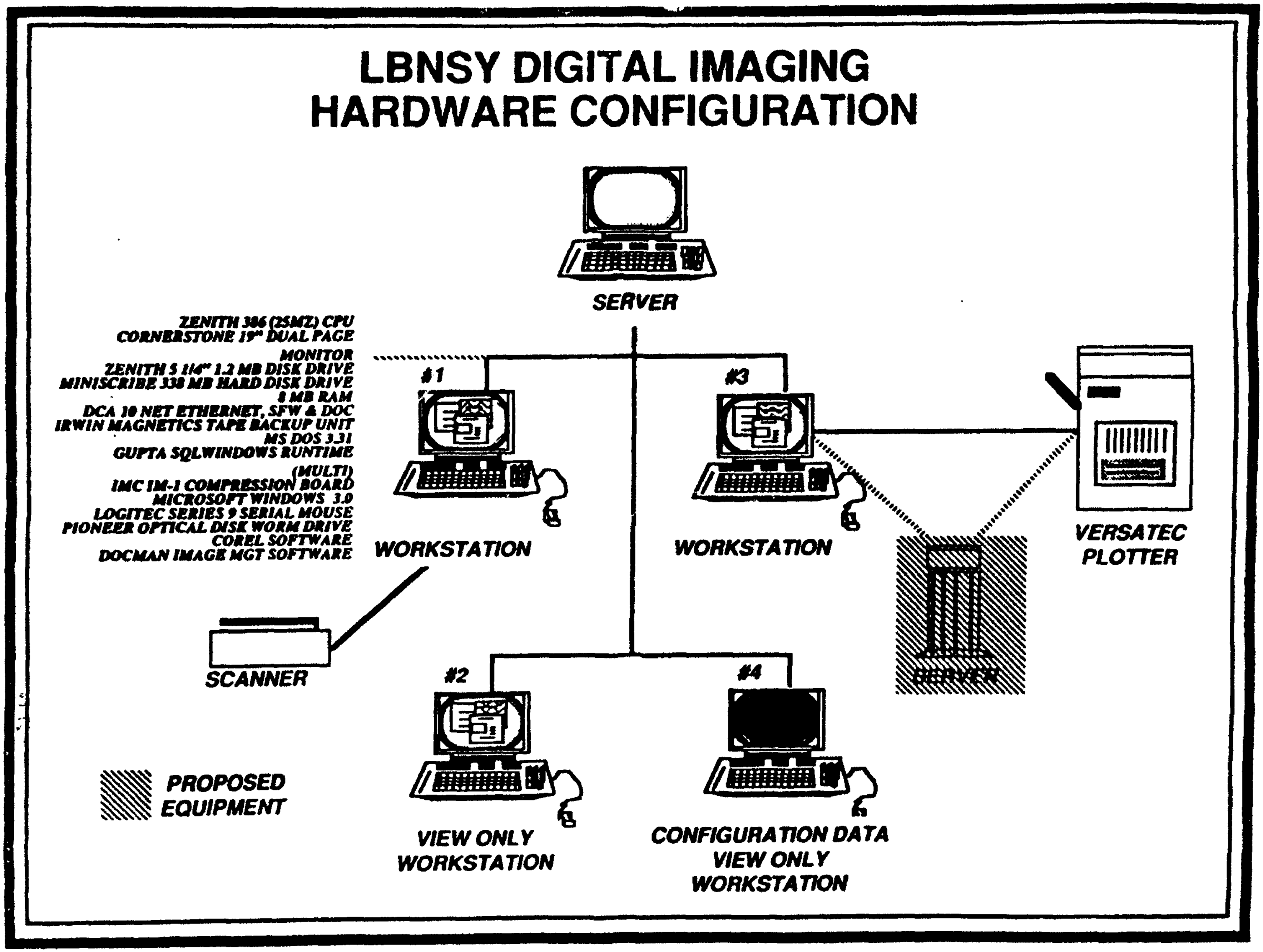

FFG-61 SHIPBOARD DIGITAL IMAGING
HARDWARE CONFIGURATION
ZENITH 386 PC (25MHZ, 5.25-INCH 1.2MB DISK DRIVE, 8MB RAM)
MINISCRIBE 330MB MAGNETIC HALF HEIGHT HARD DRIVE & CONTROLLER
IRWIN MAGNETICS TAPE BACKUP UNIT
VGA or MONOCHROME MONITOR
DCA 10NET NETWORK CARD & SOFTWARE
GUPTA SOFTWARE: SQLBase (MULTI-USER)
SERVER
CD ROM READER
HP LASERJET II PRINTER
FUJITSU SCANNER
WORKSTATION
WORKSTATION
OPTICAL SUBSYSTEM "JUKEBOX"
ZENITH 386 PC (25MHZ, 5.25-INCH 1.2MB DISK DRIVE, 8MB RAM)
MINISCRIBE 150MB MAGNETIC HALF HEIGHT HARD DRIVE & CONTROLLER
CORNERSTONE HIGH RESOLUTION MONITOR (DUAL PAGE, 19-INCH)
LOGITEC TRACKMAN FIXED POSITION MOUSE
WORM OPTICAL DISK DRIVE (PIONEER)
WORM OPTICAL DISKS (PIONEER)
LASERMASTER LASER PRINTER MEMORY BOARD
HEWLETT-PACKARD 2MB LASERJET II BOARD
DCA 10NET NETWORK CARD & SOFTWARE
SOFTWARE: MS-DOS 3.31
SOFTWARE: WINDOWS 3.0
SOFTWARE: SQLWINDOWS RUNTIME
SOFTWARE: COREL OPTICAL DISK DRIVER (RELEASE 4.0)
SOFTWARE: DOCMAN IMAGE MANAGEMENT (VIEW)
IMC IM-1 COMPRESSION BOARD (SCANNER)
PROPOSED EQUIPMENT

FIGURE 3



LBNSY DIGITAL IMAGING
HARDWARE CONFIGURATION
SERVER
ZENITH 386 (25MZ) CPU
CORNERSTONE 19" DUAL PAGE
MONITOR
ZENITH 5 1/4" 1.2 MB DISK DRIVE
MINISCRIBE 338 MB HARD DISK DRIVE
8 MB RAM
DCA 10 NET ETHERNET, SFW & DOC
IRWIN MAGNETICS TAPE BACKUP UNIT
MS DOS 3.31
GUPTA SQLWINDOWS RUNTIME
(MULTI)
IMC IM-1 COMPRESSION BOARD
MICROSOFT WINDOWS 3.0
LOGITEC SERIES 9 SERIAL MOUSE
PIONEER OPTICAL DISK WORM DRIVE
COREL SOFTWARE
DOCMAN IMAGE MGT SOFTWARE
#1
WORKSTATION
#3
WORKSTATION
VERSATEC
PLOTTER
SCANNER
#2
VIEW ONLY
WORKSTATION
#4
CONFIGURATION DATA
VIEW ONLY
WORKSTATION
PROPOSED
EQUIPMENT

FIGURE 4

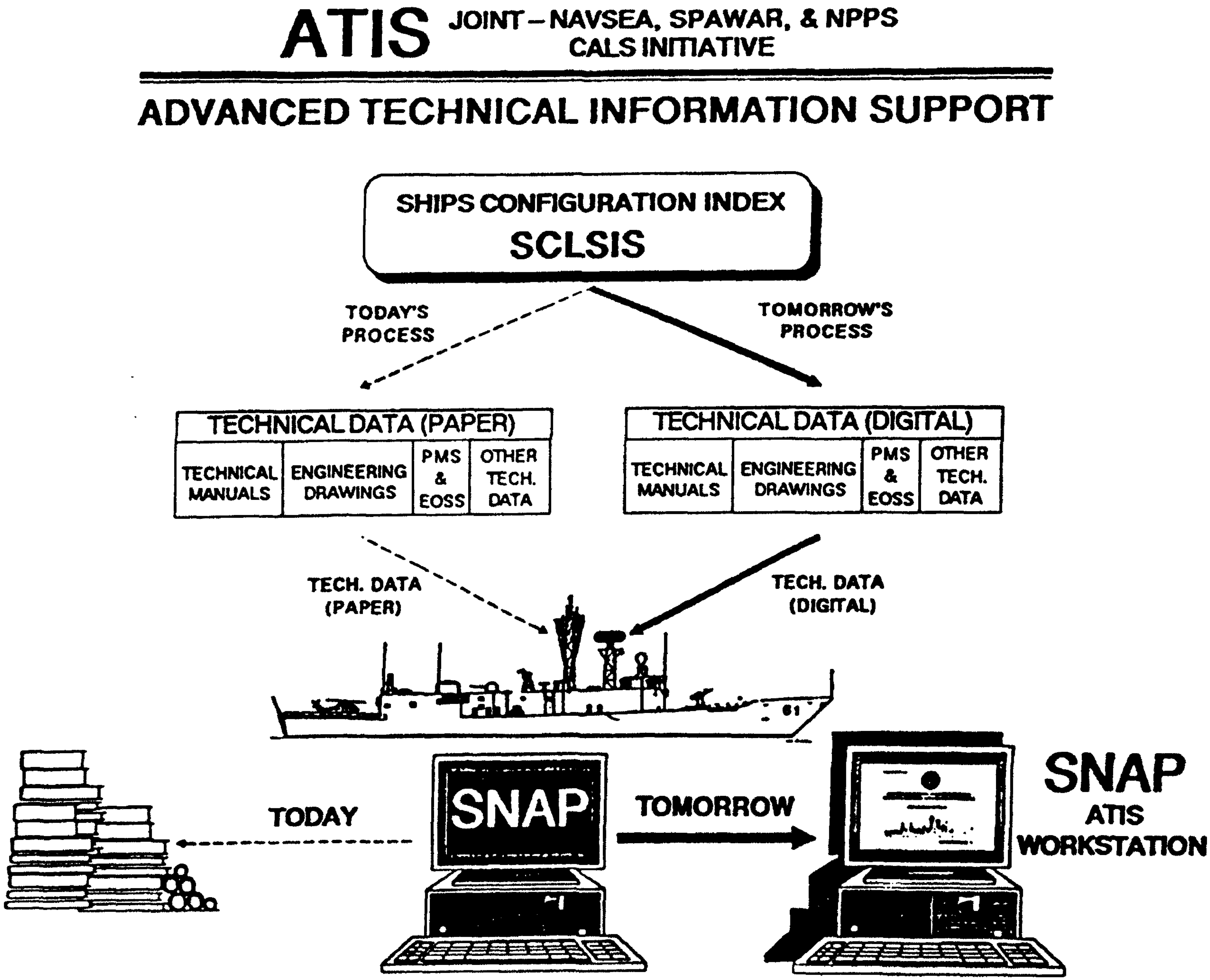

ATIS JOINT – NAVSEA, SPAWAR, & NPPS
CALS INITIATIVE
ADVANCED TECHNICAL INFORMATION SUPPORT
SHIPS CONFIGURATION INDEX
SCLSIS
TODAY'S PROCESS
TOMORROW'S PROCESS
TECHNICAL DATA (PAPER)
TECHNICAL MANUALS
ENGINEERING DRAWINGS
PMS & EOSS
OTHER TECH. DATA
TECHNICAL DATA (DIGITAL)
TECHNICAL MANUALS
ENGINEERING DRAWINGS
PMS & EOSS
OTHER TECH. DATA
TECH. DATA (PAPER)
TECH. DATA (DIGITAL)
TODAY
SNAP
TOMORROW
SNAP
ATIS WORKSTATION

FIGURE (5).

cal manuals, reduce warehouse costs, and stop the deterioration of camera ready originals of older technical manuals. This is underway. All FFG 7 Class technical manuals were scanned for this project (in a format which is compatible with and will drive the Navy's Technical Manual Print-On-Demand System). The Navy continues to scan technical manuals for distribution and reprint. This will eventually result in nearly all technical manuals being available in a digital form.

4. Begin the task of converting technical data to a digital form in order to automate the ship maintenance and modernization planning processes. Prepare for the introduction and implementation of EDMICS. With the introduction and use of ATIS at the FFG 7 Class planning activities, preparation for EDMICS is well underway, and the benefits of the program are becoming clear. The FFG 7 Class Planning Yard has reported a 20 percent reduction in the cost of drawing preparation. This reduction was attributed, in part, to FFG 61 ATIS. For the third and fourth quarters of fiscal year 1991, this savings is $588,087.00. We expect this 20 percent savings to remain constant, if not improve, in subsequent years.

5. Provide a real world prototype in order to test out emerging CALS standards and technology. This proved to be a valuable benefit of the program. The partnership established between NAVSEA PMS314, the SPAWAR Technical Data Center, NAVSEA 04TD, and other program offices, proved critical to evaluating standards, negotiating changes as necessary, and helping to determine the future direction of Navy technical data programs.

The primary lesson learned in this program was that through sticking with tested technology, and simple inexpensive processes and procedures, and by strictly applying government and industry standards, significant advances in CALS can be achieved. The FFG 61 ATIS project has advanced the cause of digital imaging programs and has made digital technical data available to the Fleet. Further progress in this area is dependent upon maintaining the spirit of cooperation which made this project possible. NAVSEA's plan for completing the transition to digital data management was discussed by Harry Felsen, NAVSEA 04TD, at the 1990 ASNE Symposium [6]. This paper represents an update of progress made toward achievement of some of the objectives discussed in his paper. Continued progress of this nature is essential toward achieving the increased efficiency demanded by the constrained fiscal environment of the 1990s.

REFERENCES

[1] History of the FFG 7 Class Shipbuilding Program, 30 June 1990.

[2] MIL-R-28002, Raster Graphics Representation in Binary Format, Requirements for

[3] MIL-M-29532(EC), Master Library Data Elements for Technical Publications, Draft

[4] Navy Implementation of Raster Scanning/Navy Image File Format, Draft

[5] NAVSEA Technical Specification 9090-700A, Ships Configuration and Logistic Support Information System

[6] NAVSEA Technical Manual Management Program: Computer-Aided Production and Management of Technical Manuals, An Overview of Plans and Issues, Harry Felsen, 1990 ASNE Paper